PB-215 937

NITROGEN AND PHOSPHORUS IN WATER. AN ANNOTATED SELECTED BIBLIOGRAPHY OF THEIR BIOLOGICAL EFFECTS

Kenneth M. Mackenthun

Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio

1965

DISTRIBUTED BY:

NTIS
National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

PB. 215 937

Nitrogen and Phosphorus in Water

An Annotated Selected Bibliography of Their Biological Effects

U.S. DEPARTMENT OF
HEALTH, EDUCATION, AND WELFARE
Public Health Service

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
U S Department of Commerce
Springfield VA 22151

Nitrogen and Phosphorus in Water

An Annotated Selected Bibliography of Their Biological Effects

by
Kenneth M. Mackenthun, *Biologist*
Technical Advisory and Investigations Section
Technical Services Branch
Division of Water Supply and Pollution Control
Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio

U.S. DEPARTMENT OF
HEALTH, EDUCATION, AND WELFARE
Public Health Service
Division of Water Supply and Pollution Control
1965

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C., 20402 - Price [illegible]

Foreword

Now, as during no other time in history, public attention is being focused more acutely on the water enrichment problem and attendant nuisance biological growths. Because the developing megalopolis and the expanding industry are pouring nutrients into the nation's waterways at an alarming rate, algal and aquatic weed nuisances have increased in areas where before they did not exist and have magnified in areas where before their growth was tolerable. The public is demanding that remedial measures be taken to make public waters bacteriologically safe and aesthetically pleasing for multiple recreational use.

This book is written for persons faced with recognizing critical nutrient concentration values for algal development and with predicting the effects of nutrient loadings on aquatic life.

Gordon E. McCallum,
Assistant Surgeon General,
Chief, Division of Water Supply and Pollution Control

Preceding page blank

Preface

For a great many years, man has been aware of the natural aging of lakes, a slow process immeasurable within the normal span of human life. Within the past quarter-century, however, the literature has documented the awareness and concern for that portion of eutrophication that is attributable to man-associated pollution. Biological nuisances including dense algal and aquatic weed growths have occurred in waters which in the past have supported only incidental populations of these plants. Plant growths in other waters have become increasingly more dense within a period of a few years. The public has become alarmed and has sought technical and sometimes legal and legislative help in rectifying local problems.

Excessive nutrients are most often blamed for the creation of plant nuisances. Among the nutrients, dominant roles have been assigned to nitrogen and phosphorus. These elements occur in natural waters, in soils, in plants and animals, and in precipitation. They are often added to water in large quantities in both domestic and industrial wastes. Wastes and fertilizers applied to land often enter watercourses and ultimately enrich those standing bodies of water whose natural physical and chemical properties encourage algal and aquatic weed development. Such growths in turn often interfere with recreation and other intended uses of water.

Investigation and research have been directed toward a solution of localized problems of accelerated eutrophication. Research and investigation will be intensified and expanded in future years. All levels of government have become vitally interested. To meet the growing needs of an expanding population, radical solutions must be found for the problem that threatens recreational and many other uses of water.

2Jc This book compiles a selected bibliography of literature with annotations specifically directed toward nitrogen and phosphorus and the ramifications of these and closely associated elements in the aquatic environment. Related intimately to the aquatic environment is the soil environment, the nutrients deposited thereon, and the atmosphere. These have not been neglected. Freshwater investigations have received preferential treatment but marine investigations and research have been considered as such may relate or furnish clues to the solution of problems in freshwater. →P VI

✓

Preceding page blank

This book was compiled for the engineer and the scientist who are faced with predicting limnological changes resulting from nutrient loadings to standing bodies of water, with recognizing critical concentration values for algal development, and with predicting the effects of fertilizers on aquatic life. Information is given on expected contributions from various nutrient sources, aquatic standing crops and production rates, and the nitrogen and phosphorus content or concentration in plants and animals. This compilation is a beginning, not an end. It will be supplemented as additional data are amassed.

Cincinnati, Ohio
May 1, 1965

SUBJECT INDEX

ALGAE: Page
- Biochemical Oxygen Demand of:
  - Lackey, 1958 49
  - Mackenthun et al., 1964 54
- Bloom, Definition of:
  - Anon., 1949 10
  - Lackey, 1945, 1949 49
- Chlorophyll, Chemical Content:
  - Anderson, 1961 8
- Crude Protein in:
  - Phinney and Peek, 1961 80
- Nitrogen and Phosphorus in:
  - Birge and Juday, 1922 15
  - Gerloff and Skoog, 1954 30
  - Phinney and Peek, 1961 80
  - Redfield et al., 1963 86
  - Schuette and Alder, 1929b 97
- Effects of:
  - Beneficial:
    - Lackey, 1958 49
  - Harmful:
    - Bennett, 1962 13
    - Lackey, 1958 49
    - Sylvester and Anderson, 1964 99
- Iron and Manganese in:
  - Gerloff and Skoog, 1957a 31
- Limiting Factors:
  - Allen, 1955 7
  - Chu, 1942, 1943 19
  - Gerloff and Skoog, 1957 31
  - Harvey, 1960 34
  - Hutchinson, 1957 41
  - Moore, 1958 72
  - Müller, 1953 73
  - Neess, 1949 73
  - Prescott, 1960 82
  - Provasoli, 1961 83
  - Sawyer, 1947, 1952, 1954 94, 95
  - Whitford and Phillips, 1959 110

ALGAE—Continued
Kinds of:
Anabaena: Page
Birge and Juday, 1922 15
Dugdale and Dugdale, 1962 25
Dugdale et al., 1964 26
Goering and Neess, 1964 32
Prescott, 1960 82
Aphanizomenon:
Phinney and Peek, 1961 80
Prescott, 1960 82
Sawyer and Ferullo, 1961 96
Botryococcus braunii:
McKee, 1962 67
Ceratium:
Lackey, 1945 49
Chara:
Schuette and Alder, 1929b 97
Chlorella:
Allen, 1955 7
Cook, 1962 20
Lackey, 1945 49
McKee, 1962 67
Cladophora:
Birge and Juday, 1922 15
Prescott, 1960 82
Micractinum:
Lackey, 1958 49
Microcystis aeruginosa:
Birge and Juday, 1922 15
Gerloff and Skoog, 1954 30
Goering and Neess, 1964 32
Prescott, 1960 82
Nitzschia closterium:
McKee, 1962 67
Oscillatoria:
Mackenthun et al., 1960 57
Oscillatoria rubescens:
Anderson, 1961 8
Hasler, 1947 35
McKee, 1962 67
Pandorina morum:
Lackey, 1945 49

ALGAE—Continued
- Kinds of—Continued
  - *Phaeodactylum:*
    - Harvey, 1960 — Page 34
  - *Rhizoclonium:*
    - Mackenthun et al., 1960 — 57
  - *Scenedesmus:*
    - Allen, 1955 — 7
    - Cook, 1962 — 20
  - *Spirogyra:*
    - Prescott, 1960 — 82
  - *Stigeoclonium:*
    - Mackenthun et al., 1960 — 57
  - *Synechococcus cedrorum:*
    - McKee, 1962 — 67
  - *Trichodesmium:*
    - Dugdale et al., 1964 — 26
  - *Ulva:*
    - Lackey, 1958 — 49
  - *Volvox:*
    - Birge and Juday, 1922 — 15
- Nutrient Values Required for Blooms:
  - Gerloff and Skoog, 1954, 1957a — 30, 31
  - Prescott, 1960 — 82
  - Sawyer, 1947, 1952, 1954 — 94, 95
  - Sylvester, 1961 — 98
- Oxidation Ponds, Algae in:
  - Allen, 1955 — 7
  - Mackenthun, 1962 — 52
  - Porges and Mackenthun, 1963 — 80
  - Parker, 1962 — 79
- Production:
  - Allen, 1955 — 7
  - Birge and Juday, 1922 — 15
  - Gerloff and Skoog, 1957 — 31
  - Gotaas, 1954 — 32
  - Lackey, 1958 — 49
  - Mackenthun et al., 1960 — 57
  - Parker, 1962 — 79
- Vitamins required:
  - Burkholder and Burkholder, 1956 — 17
  - Cook, 1962 — 20
  - Guillard and Cassie, 1963 — 33
  - Menzel and Spaeth, 1962 — 68
  - Provasoli, 1961, 1963 — 83

ANIMALS:
- *Cyclops:* Page
  - Birge and Juday, 1922 15
- *Glyptotendipes paripes:*
  - Provost, 1958 84
- *Chironomus tentans:*
  - Birge and Juday, 1922 15
- *Daphnia pulex:*
  - Birge and Juday, 1922 15

CHEMISTRY:
- Carbon-Nitrogen ratios:
  - Provasoli, 1963 83
- Hypolimnetic Oxygen Deficit:
  - Anderson, 1961 8
- Iron-Manganese:
  - Gerloff and Skoog, 1957a 31
- Oxygen-Nutrients:
  - Millar, 1955 70
  - Tucker, 1957a 102
- Phosphate, Definition of Terms:
  - Benoit, 1955 14
- Phosphorus—Iron:
  - Hasler and Einsele, 1948 36
  - Tanner, 1960 101
  - Tucker, 1957a 102
- Phosphorus—Arsenic:
  - Mackenthun, unpublished 53
- Phosphorus, Utilization by Algae:
  - Krauss, 1958 47
  - Rice, 1953 87

EUTROPHICATION:
- Cause:
  - Ohle, 1953 77
- Definition:
  - Hasler, 1947 35
- History:
  - Hasler, 1947 35
- Rate:
  - Hasler and Einsele, 1948 36
  - Tanner, 1960 101

FERTILIZATION, ARTIFICIAL:
- Effects on:
  - Algae:
    - Ball, 1950 12
    - Ball and Tanner, 1951 13
    - Hooper and Ball, 1964 39

FERTILIZATION, ARTIFICIAL—Continued
- Effects on—Continued
  - Bottom Organisms: Page
    - Ball, 1949 12
    - McIntire and Bond, 1962 66
  - Fish Production:
    - Andrews, 1947 8
    - Ball, 1949 12
    - Ball and Tanner, 1951 13
    - Bennett, 1962 13
    - Borgstrom, 1961 16
    - Odum, 1959 74
    - Swingle and Smith, 1939 98
  - Hypolimnetic Oxygen:
    - Tanner, 1960 101
  - Plankton:
    - Ball, 1949 12
    - McIntire and Bond, 1962 66
  - Thermocline:
    - Tanner, 1960 101
  - Total Alkalinity:
    - Tanner, 1960 101
  - Winterkill:
    - Ball, 1950 12
    - Ball and Tanner, 1951 13
- Rate of Application to Land:
  - Andrews, 1947 8
  - Anon., 1964a 11
  - Donahue, 1961 23
  - Ignatieff and Page, 1958 42
  - Lackey and Sawyer, 1945 50
  - Mikkelsen et al., 1962 69
  - Millar, 1955 70
- Rate of Application to Water:
  - Andrews, 1947 8
  - Ball, 1949, 1950 12
  - Ball and Tanner, 1951 13
  - Hasler and Einsele, 1948 36
  - Hooper and Ball, 1964 39
  - Tanner, 1960 101

FERTILIZATION BY DUCKS:
- Lackey, 1958 49
- Paloumpis and Starrett, 1960 79
- Sanderson, 1953 93
- Sylvester and Anderson, 1964 99

LAKES:
- Douglas Lake, Michigan: Page
  - Tucker, 1957, 1957a 102
- Lake Erie:
  - Burkholder, 1929 17
  - Chandler and Weeks, 1945 18
  - Curl, 1959 21
- Green Lake, Washington:
  - Sylvester, 1961 98
  - Sylvester and Anderson, 1964 99
- Green Lake, Wisconsin:
  - Rickett, 1924 89
- Upper Klamath Lake, Oregon:
  - Phinney and Peek, 1961 80
- Lake Mendota, Wisconsin:
  - Anon., 1949 10
  - Birge and Juday, 1922 15
  - Domogalla et al., 1925, 1926a 23
  - Schuette, 1918 97
- Lake Michigan:
  - Domogalla et al., 1926a 23
- Lake Superior:
  - Putnam and Olson, 1959, 1960 85
- Lake Tahoe, California-Nevada:
  - Ludwig et al., 1964 52
- Lake Washington, Washington:
  - Anderson, 1961 8
- Lake Zoar, Connecticut:
  - Benoit and Curry, 1961 14
  - Curry and Wilson, 1955 21

MIDGES:
- Cause and Control:
  - Provost, 1958 84

NITRATE POISONING:
- Livestock:
  - Tucker et al., 1961 103
  - Winks et al., 1950 110
- Methemoglobinemia:
  - Anon., 1950 11
  - Bosch et al., 1950 16
  - Campbell, 1952 18
  - Comly, 1945 20
  - Sattelmacher, 1962 93
  - Walton, 1951 108

NITROGEN FIXATION BY ALGAE: Page
- Dugdale and Dugdale, 1962, 1965 .... 25, 26
- Dugdale and Neess, 1961 26
- Dugdale et al., 1964 26
- Goering and Neess, 1964 32
- Krauss, 1958 47
- McKee, 1962 67
- Sawyer and Ferullo, 1961 96

NITROGEN AND PHOSPHORUS:
- Content of or Concentration in:
  - Agricultural Drainage:
    - Engelbrecht and Morgan, 1961 28
    - Sawyer, 1947 94
  - Basic Sources:
    - Mackenthun et al., 1964 54
  - Benthos:
    - Birge and Juday, 1922 15
    - Vallentyne, 1952 106
  - Crops:
    - Ignatieff and Page, 1958 42
  - Culture Solutions:
    - Douglas, 1959 25
    - Fitzgerald, 1965 29
    - Gerloff et al., 1950 30
    - Saunby, 1953 93
  - Fishes:
    - Beard, 1926 13
    - Borgstrom, 1961 16
    - Love et al., 1959 51
    - McGauhey et al., 1963 59
    - Sylvester and Anderson, 1964 99
  - Forest Streams:
    - Sylvester, 1961 98
  - Ground Water:
    - Juday and Birge, 1931 44
  - Irrigation Returns:
    - Sylvester, 1961 98
    - Sylvester and Seabloom, 1963 100
  - Lakes:
    - Anderson, 1961 8
    - Benoit, 1955 14
    - Benoit and Curry, 1961 14
    - Burkholder, 1929 17
    - Chandler and Weeks, 1945 18
    - Curl, 1959 21
    - Curry and Wilson, 1955 21

NITROGEN AND PHOSPHORUS—Continued
  Content of or Concentration in—Continued
    Lakes—Continued — Page
      Domogalla and Fred, 1926 — 22
      Domogalla et al., 1925, 1926a — 23
      Engelbrecht and Morgan, 1959 — 27
      Hutchinson, 1957 — 41
      Juday and Birge, 1931 — 44
      Juday et al., 1927 — 44
      Moyle, 1956 — 72
      Putnam and Olson, 1959, 1960 — 85
      Rigler, 1964 — 90
      Sawyer, 1947 — 94
      Sawyer et al., 1945 — 96
      Sylvester, 1961 — 98
      Tucker, 1957 — 102
      Whipple et al., 1948 — 110
    Land Drainage:
      Abbott, 1957 — 7
      Anon., 1949, 1964b — 10, 11
      Engelbrecht and Morgan, 1959 — 27
      Mackenthun et al., 1964 — 54
    Manures:
      Andrews, 1947 — 8
      Anon., 1964 — 11
      Donahue, 1961 — 23
      Ignatieff and Page, 1958 — 42
      Millar, 1955 — 70
      Rodale, 1960 — 90
      VanVuran, 1948 — 106
    Oceans:
      Ryther, 1963 — 92
    Plankton:
      Birge and Juday, 1922 — 15
      Harris and Riley, 1956 — 33
      Schuette, 1918 — 97
      Vaccaro, 1964 — 105
    Plants, Algae:
      Gerloff and Skoog, 1954 — 30
      Kevern and Ball, 1965 — 45
      Phinney and Peek, 1961 — 80
      Prescott, 1960 — 82
      Schuette and Alder, 1929b — 97

NITROGEN AND PHOSPHORUS—Continued
- Content of or Concentration in—Continued
  - Plants, Other: Page
    - Harper and Daniel, 1939 ---- 33
    - Ignatieff and Page, 1958 ---- 42
    - Millar, 1955 ---- 70
    - Rodale, 1960 ---- 90
    - Schuette and Alder, 1928, 1929a ---- 97
    - VanVuran, 1948 ---- 106
  - Pollens:
    - McGauhey et al., 1963 ---- 59
  - Precipitation:
    - Chalupa, 1960 ---- 18
    - Hutchinson, 1957 ---- 41
    - Matheson, 1951 ---- 58
    - McKee, 1962 ---- 67
    - Meyer and Pampfer, 1959 ---- 69
    - Miller, 1961 ---- 71
    - Moore, 1958 ---- 72
    - Putnam and Olson, 1960 ---- 85
    - Tamm, 1951, 1953 ---- 100, 101
    - Voigt, 1960 ---- 107
  - Sawdust:
    - Donahue, 1961 ---- 23
  - Sediments, Benthic:
    - Holden, 1961 ---- 39
    - Juday et al., 1941 ---- 45
    - Mackenthun et al., 1964 ---- 54
    - McGauhey et al., 1963 ---- 59
    - Sylvester and Anderson, 1964 ---- 99
  - Sewage:
    - Engelbrecht and Morgan, 1959 ---- 27
    - McGauhey et al., 1963 ---- 59
    - Owen, 1953 ---- 78
    - Parker, 1962 ---- 79
    - Rudolfs, 1947 ---- 92
    - Sawyer, 1947, 1952 ---- 94
    - Stumm and Morgan, 1962 ---- 98
    - VanVuran, 1948 ---- 106
  - Sewage Effluents:
    - Engelbrecht and Morgan, 1959 ---- 27
    - Mackenthun et al., 1960, 1964 ---- 54, 57
    - Rudolfs, 1947 ---- 92
  - Sewage Sludge:
    - Rodale, 1960 ---- 90

NITROGEN AND PHOSPHORUS—Continued
- Content of or Concentration in—Continued
  - Soils: Page
    - Deevey, 1940 22
    - Donahue, 1961 23
    - Juday and Birge, 1931 44
    - Mikkelsen et al., 1962 69
    - Millar, 1955 70
    - Ryther, 1963 92
    - Walton, 1951 108
  - Stabilization Ponds:
    - Porges and Mackenthun, 1963 80
  - Streams:
    - Engelbrecht and Morgan, 1959 27
    - Mackenthun, 1962 52
    - Mackenthun et al., 1960 57
    - Putnam and Olson, 1959, 1960 85
  - Street Drains:
    - Sylvester, 1961 98
  - Terms, Definition:
    - Benoit, 1955 14
    - Odum, 1959 74
  - Tree Leaves:
    - Donahue, 1961 23
    - Engelbrecht and Morgan, 1959 27
  - Urban Runoff:
    - Weibel et al., 1964 109
- Critical Growth Values:
  - Gerloff and Skoog, 1954 30
  - Moore, 1958 72
  - Müller, 1953 73
  - Sawyer, 1947, 1952, 1954 94, 95
  - Sylvester, 1961 98
- Cycle in Lakes, Phosphorus:
  - Hutchinson, 1957 41
- Effects on Fish Production:
  - Moyle, 1956 72
- Excretion by Organisms:
  - Johannes, 1964a, 1964b, 1964c 43, 44
  - Kuenzler, 1961 48
  - Millar, 1955 70
  - Pomeroy et al., 1963 80
  - Provasoli, 1963 83
- Law of Minimum:
  - Millar, 1955 70
  - Redfield et al., 1963 86

NITROGEN AND PHOSPHORUS—Continued
  Loading to Lakes: Page
    Anderson, 1961 8
    Anon., 1949 10
    Benoit and Curry, 1961 14
    Curl, 1959 21
    Hasler, 1947 35
    Lackey and Sawyer, 1945 50
    Ludwig et al., 1964 52
    Mackenthun, 1962 52
    Sawyer, 1947 94
    Sylvester and Anderson, 1964 99
  Losses from Soils:
    Andrews, 1947 8
    Fippin, 1945 29
  Production in United States:
    Ignatieff and Page, 1958 42
    McVicker et al., 1963 68
  Retention in Lakes:
    Hasler, 1947 35
    Ludwig et al., 1964 52
    Mackenthun, 1962 52
    Sawyer, 1947 94
    Sylvester and Anderson, 1964 99
  Released from Bottom Sediments:
    Hasler, 1957 35
    Hayes et al., 1952 37
    Holden, 1961 39
    Hooper and Elliott, 1953 40
    MacPherson et al., 1958 58
    Neess, 1949 73
    Ohle, 1953 77
    Sylvester and Anderson, 1964 99
    Wurtz, 1962 111
    Zicker et al., 1956 111
  Released from Decomposing Plankton:
    Grill and Richards, 1964 32
    Provasoli, 1963 83
  Released from Hypolimnion:
    Hayes and Beckett, 1956 36
  Removal from Sewage:
    Curry and Wilson, 1955 21
    Hasler and Einsele, 1948 36
    Lea, Rohlich and Katz, 1954 50
    Malhotra et al., 1964 58
    McGauhey et al., 1963 59

NITROGEN AND PHOSPHORUS—Continued
  Removal from Sewage—Continued — Page
    Neil, 1957 — 74
    Ohle, 1953 — 77
    Owen, 1953 — 78
    Rohlich, 1961 — 91
    Sawyer, 1952 — 94
    VanVuren, 1948 — 106
  Removal in Stabilization Ponds:
    Porges and Mackenthun, 1963 — 80
    Stumm and Morgan, 1962 — 98
  Turnover Rate and Time:
    Hayes et al., 1952 — 37
    Odum, 1959 — 74
    Rigler, 1956 — 89
    Zilversmit et al., 1943 — 111
  Utilization by Plankton:
    Abbott, 1957 — 7
    Chu, 1942, 1943 — 19
    Dugdale and Dugdale, 1965 — 26
    Flaigg and Reid, 1954 — 29
    Harvey, 1960 — 34
    Hoagland, 1944 — 38
    Hoffman and Olive, 1961 — 38
    Kratz and Myers, 1955 — 47
    Krauss, 1958 — 47
    McKee, 1962 — 67
    Overbeck, 1961 — 78
    Pratt, 1950 — 81
    Provasoli and Pintner, 1960 — 84
    Redfield et al., 1963 — 86
    Rice, 1953 — 87
    Rigler, 1956 — 89
    Webster, 1959 — 109
ORGANISM STANDING CROPS:
  Bottom Organisms:
    Ludwig et al., 1964 — 52
    Mackenthun et al., 1964 — 54
  Fish:
    Moyle, 1956 — 72
  Higher Aquatic Plants:
    Low and Bellrose, 1944 — 51
    Rickett, 1922, 1924 — 88, 89

ORGANISM STANDING CROPS—Continued
Plankton: Page
Anderson, 1961 — 8
Birge and Juday, 1922 — 15
Gotaas, 1954 — 32
Mackenthun et al., 1960 — 57
Prescott, 1960 — 82
Redfield et al., 1963 — 86
PLANTS, HIGHER AQUATIC:
Castalia odorata:
Schuette and Alder, 1929 — 97
Myriophyllum:
Birge and Juday, 1922 — 15
Najas flexilis:
Schuette and Alder, 1929 — 97
Potamogeton:
Schuette and Alder, 1928 — 97
Potamogeton americanus:
Low and Bellrose, 1944 — 51
Vallimeria:
Schuette and Alder, 1928 — 97
PRODUCTION:
Macrophytes:
Knight and Ball, 1962 — 46
Odum, 1959 — 74
Ryther, 1963 — 92
VanVuran, 1948 — 106
Periphyton:
Knight and Ball, 1962 — 46
Phytoplankton:
Knight and Ball, 1962 — 46
Krauss, 1958 — 47
Parker, 1962 — 79
Stumm and Morgan, 1962 — 98
Primary:
Ludwig et al., 1964 — 52
Odum, 1959 — 74
Ryther, 1963 — 92

Author Index

Abbott, W. 1957*
Adeney, W. E. 1908 (See Lackey, 1958)
Alder, H. 1928, 1929a, 1929b
Al Kholy, A. A. 1956 (See Krauss, 1958)
Allee, W. C. 1949 (See Moore, 1958)
Allen, M. B. 1952 (See McKee, 1962; See Fitzgerald, 1965), 1955*
Allum, M. O. 1957 (See Odum, 1959)
Alway, F. J. 1930 (See Donahue, 1961)
Anderson, G. C. 1961*, 1964
Anderson, R. J. 1964
Andrews, W. B. 1947*
Anon. 1949*, 1950*, 1964*, 1964a*, 1964b*
Ashton, F. M. 1957 (See Odum, 1959)
Atkins, W. R. G. 1923 and 1925 (See Prescott, 1960)
Ball, R. C. 1949* (Also see Mackenthun et al., 1964), 1950*, 1951*, 1962, 1964, 1965
Barnes, O. K. 1942 (See Odum, 1959)
Bartsch, A. F. 1957 (See Odum, 1959)
Bay, C. E. 1957 (See Mackenthun et al., 1964)
Beard, H. R. 1926*
Beckett, N. R. 1956
Bellrose, F. C., Jr. 1944
Bennett, G. W. 1962*
Benoit, R. J. 1955*, 1961*
Berger, K. C. 1956
Berry, L. J. 1961
Bineau, A. 1856 (See McKee, 1962)
Birge, E. A. 1922*, 1927, 1931 (See Benoit, 1955), 1931, 1934 (See Provasoli, 1963), 1941
Bond, C. E. 1962
Borgstrom, G. 1961*
Bosch, H. M. 1950*
Boury, M. 1936 (See Borgstrom, 1961)
Brehmer, M. L. 1960 (See Knight and Ball 1962)

---

*Sole or Senior Author.

Brenson, J. C	1962 (See McGauhey et al., 1963)
Bridger, G. L	1963
Brodie, H. W	1957 (See Odum, 1959)
Bumpus, D. H	1949 (See Moore, 1958)
Burkholder, L. M	1956
Burkholder, P	1929*
Burkholder, P. R	1956*
Burlew, J. S	1953 (See Fitzgerald, 1965)
Burr, G. O	1957 (See Odum, 1959)
Bush, A. F	1954 (See Mackenthun et al., 1964)
Cameron, M. L	1952
Campbell, J	1935 (See Borgstrom, 1961)
Campbell, W. A. B	1952*
Carter, R. C	1964
Cassie, V	1963
Chalupa, J	1960*
Chandler, D. C	1945*
Chandler, R. F., Jr	1941, 1943 (See Donahue, 1961)
Chu, S. P	1942* (Also see McKee, 1962), 1943*
Coleman, R. E	1957 (See Odum, 1959)
Comly, H. H	1945* (Also see Walton, 1951)
Cook, B. B	1962*
Cooper, L. H. N	1941 (See Hooper and Elliott, 1953; Also see Mackenthun et al., 1964)
Cooper, R. C	1962 (See McGauhey et al., 1963)
Cordy, D. R	1961
Corlett, J	1957 (See Knight and Ball, 1962)
Cramer, M	1948
Cree, H. K	1962 (See McGauhey et al., 1963)
Curl, H	1959*
Curry, J. J	1955*, 1961
Cutting, C. L	1943 (See Borgstrom, 1961), 1952 (See Odum, 1959)
Daniel, H. R	1939
De, P. K	1956 (See Krauss, 1958)
Deevey, E. S., Jr	1940*
Dietz, J. C	1958 (See Engelbrecht and Morgan, 1959)
Dineen, C. F	1953 (See Mackenthun et al., 1964)
Domogalla, B. P	1925*, 1926*, 1926a*
Donahue, R. L	1961*
Douglas, J. S	1959*
Dugdale, R. C	1961*, 1962, 1964*, 1965
Dugdale, V. A	1962*, 1965*

---

*Sole or Senior Author.

Eck, P.	1957 (See Mackenthun et al., 1964)
Einsele, W. G.	1938 (See Tanner, 1960), 1941 (See McKee, 1962), 1948
Eliassen, R.	1963
Elliott, A. M.	1953 (Also see Mackenthun et al., 1964)
Emerson, A. E.	1949 (See Moore, 1958)
Engelbrecht, R. S.	1959*, 1961*
Entenman, C.	1943
Fair, G. M.	1948
Ferullo, A. F.	1961
Fippin, E. O.	1945*
Fishler, M. C.	1943
Fitzgerald, G. P.	1950, 1952 (See Fitzgerald, 1965), 1961 (See McGauhey et al., 1963), 1965*
Flaigg, N. G.	1954*
Fogg, G. E.	1951 (See Krauss, 1958), 1952 (See Provasoli, 1963), 1954 (See McKee, 1962)
Frazier, W. C.	1940 (See Walton, 1951)
Fred, E. B.	1926, 1926a
Fuller, T. C.	1961
Gerloff, G. C.	1950*, 1952 (See Fitzgerald, 1965), 1954*, 1957*, 1957a*
Glancy, J. B.	1949 (See Lackey, 1958)
Goering, J. J.	1964* (2)
Golneke, C. G.	1962 (See McGauhey et al., 1963)
Gorham, P. R.	1958 (See Fitzgerald, 1965), 1961 (See Fitzgerald, 1965)
Gotaas, H. B.	1954*
Grill, E. V.	1964*
Grzenda, A. R.	1960 (See Knight and Ball, 1962)
Guillard, R. R. L.	1963*
Harmenson, R. H.	1958 (See Engelbrecht and Morgan, 1959)
Harper, H. J.	1939*
Harris, E.	1956* (Also see Vaccaro, 1946)
Hartt, H. E.	1957 (See Odum, 1959)
Harvey, H. W.	1926 (See Redfield et al. 1963), 1953 (See Krauss, 1958), 1960*
Harvey, W. A.	1961
Hasler, A. D.	1947*, 1948*, 1956, 1957*
Hausteen, B.	1899 (See McKee, 1962)
Hayes, F. R.	1952*, 1956*, 1958
Hayes, O. E.	1957 (See Mackenthun et al., 1964)
Helfrich, P.	1957 (See Odum, 1959)
Hickling, C. F.	1948 (See Odum, 1959)

---

*Sole or Senior Author.

Hoagland, D. R.	1944*
Hoffman, D. A.	1961*
Hogetsu, K.	1954 (See Odum, 1959)
Holden, A. V.	1961*
Hooper, F. F.	1953* (Also see Mackenthun et al., 1964), 1964*
Hughes, E. O.	1958 (See Fitzgerald, 1965)
Hutchinson, G. E.	1941 (See Benoit, 1955; Hooper and Elliott, 1953), 1957*
Ichimura, S.	1954 (See Odum, 1959)
Ignatieff, V.	1958*
Ingram, W. M.	1964
Jackson, M. L.	1957 (See Mackenthun et al., 1964)
Johannes, R. E.	1964a*, 1964b*, 1964c*
Jones, N. R.	1959
Juday, C.	1922, 1925, 1927*, 1931 (See Benoit, 1955), 1931*, 1934 (See Provasoli, 1963), 1940 (See Odum, 1959), 1941*
Kamen, M. D.	1948
Katz, W. J.	1954
Kazmierczak, E.	1964
Kemmerer, G. I.	1927
Ketchum, B. H.	1939a, 1949 (See Redfield et al., 1963) (See Harvey, 1960; Rice, 1953), 1939b (See Harvey, 1960; Rice, 1953), 1963
Kevern, N. R.	1965*
Knight, A.	1962*
Kohn, A. J.	1957 (See Odum, 1959)
Kortschak, H. P.	1957 (See Odum, 1959)
Krantz, B. A.	1961
Kratz, W. A.	1955* (Also see Krauss, 1958)
Krauss, R. W.	1958*
Kuenzler, E. J.	1961*
Kuhn, P. A.	1956 (See McGauhey et al., 1963)
Lackey, J. B.	1945, 1945* (Also see Anon., 1949), 1949* (Also see Lackey, 1958), 1958*
Lang, R.	1942 (See Odum, 1959)
Lea, W. L.	1950 (See Sawyer, 1952), 1954*
Lee, G. F.	1964
Lenz, R. T.	1945 (Also see Mackenthun et al., 1964)
Letts, E. A.	1908 (See Lackey, 1958)
Liebig, J.	1849 (See Millar, 1955)
Lindeman, R. L.	1941 (See Odum, 1959)
Livingstone, D. A.	1952

---

*Sole or Senior Author.

Love, R. M.	1959*
Lovern, J. A.	1959
Low, J. B.	1944*
Ludwig, H. F.	1963, 1964*
Lueck, B. F.	1956 (See Mackenthun et al., 1964)
Lueschow, L. A.	1960
Lund, H. A.	1948 (See Donahue, 1961)
MacFarlane, C.	1952 (See Odum, 1959)
MacPherson, L. B.	1958*
Mackenthun, K. M.	1960,* 1961 (See Mackenthun et al., 1964), 1962,* Unpublished,* 1963, 1964*
Mackereth, F. J.	1953 (See Krauss, 1958)
Malhotra, S. K.	1964*
Mandal, L. N.	1956 (See Krauss, 1958)
Martin, W. E.	1962
Matheson, D. H.	1951*
Mathews, H. M.	1963
McCarter, J. A.	1952
McCarter, J. R.	1940 (See Walton, 1951)
McDermott, J. H.	1961 (See Porges and Mackenthun, 1963)
McGauhey, P. H.	1963*
McIntire, C. D.	1962*
McKee, H. S.	1962*
McLachlan, J.	1961 (See Fitzgerald, 1965)
McNabb, C. D.	1960 (See Mackenthun et al., 1964)
McVicker, M.	1963*
Meloche, V. W.	1941
Menzel, D. W.	1962*
Metz, L. J.	1954 (See Donahue, 1961)
Metzler, D. F.	1958 (See Mackenthun et al., 1964)
Meyer, J.	1948 (See McKee, 1962), 1959*
Mikkelsen, D. S.	1962*
Millar, C. E.	1955*
Miller, M. D.	1962*
Miller, R. B.	1961
Min, H. S.	1963
Monday, C. A., Jr.	1961 (See Porges and Mackenthun, 1963)
Moore, G. M.	1939 (See Hooper and Elliott, 1953)
Moore, H. B.	1958*
Morgan, J. J.	1959, 1961, 1962
Mortimer, C. H.	1941 (See Tanner, 1960)
Moyle, J. B.	1940 (See Mackenthun et al., 1964), 1956*, 1961 (See Mackenthun et al., 1964)
Mulford, S. F.	1954 (See Mackenthun et al., 1964)

---

*Sole or Senior Author.

Müller, W.	1951*
Myers, J.	1955 (Also see Krauss, 1958)
Needham, P. R.	1958 (See Mackenthun et al., 1964)
Neel, J. K.	1961 (See Porges and Mackenthun, 1963)
Neess, J. C.	1949*, 1961, 1964
Negelein, E.	1920 (See McKee, 1962)
Neil, J. H.	1957
Nelson, L. B.	1963
Nesselson, E. J.	1954 (See McGauhey et al., 1963)
Odum, H. T.	1957 (Also see Odum, 1959) (See Knight, and Ball, 1962), 1959
Odum, E. P.	1957 (See Odum, 1959), 1959*
Ohle, W.	1953*
Olive, J. R.	1961
Olson, T. A.	1959, 1960
Oswald, W. J.	1962 (See McGauhey et al., 1963)
Overbeck, J.	1961*
Ovington, J. D.	1956 (See Odum, 1959), 1957 (See Odum, 1959)
Owen, R.	1953 (Also see McGauhey et al., 1963)
Page, H. J.	1958
Paloumpis, A. A.	1960*
Pampfer, E.	1959
Park, O.	1949 (See Moore, 1958)
[illegible]k, T.	1949 (See Moore, 1958)
Parker, C. D.	1962* (Also see McGauhey et al., 1963)
Pearsall, W. H.	1956 (See Odum, 1959)
Pearson, E. A.	1963
Peek, C. A.	1961
Penfound, W. T.	1956 (See Odum, 1959)
Peterson, W. H.	1925, 1926a
Phillips, R. C.	1959
Phinney, H. K.	1961*
Pintner, I. J.	1960
Pomeroy, L. R.	1963
Porges, R.	1963*, 1964
Pratt, D. M.	1950*
Prescott, G. W.	1960*
Provasoli, L.	1960*, 1961*, 1963*
Provost, M. W.	1958
Putnam, H. D.	1959*, 1960*
Rawson, D. S.	1952 (See Odum, 1959)
Reay, G. A.	1943 (See Borgstrom, 1961)
Redfield, A. C.	1963*

---

*Sole or Senior Author.

Reid, G. W	1954
Renn, C. E	1937 (See Hooper and Elliott, 1953)
Rice, T. R	1953* (Also see Krauss, 1958)
Richards, F. A	1963, 1964
Rickett, H. W	1922* (Also see Knight and Ball, 1962), 1924* (Also see Knight and Ball, 1962)
Rigler, F. H	1956* (Also see Rigler, 1964), 1964*
Riley, G. A	1949 (See Moore, 1958), 1951 (See Ryther, 1963), 1956 (Also see Vaccaro, 1964; Also see Odum, 1959), 1957 (See Knight and Ball, 1962; Also see Odum, 1959)
Robinson, R. J	1927
Rodale, J. I	1960*
Rohde, W	1948 (See Moore, 1958)
Rohlich, G. A	1950 (See Sawyer, 1952), 1954, 1961* (See McGauhey et al., 1963), 1963, 1964
Rosenfield, A. B	1950
Rousenfell, G. A	1946 (See Odum, 1959)
Rudolfs, W	1947* (Also see Sawyer, 1952; Also see Engelbrecht and Morgan, 1959)
Ryther, J. H	1960 (See Redfield et al., 1963) 1963*, 1964
Salisbury, R. M	1950
Sanderson, W. W	1953*
Sarles, W. B	1940 (See Walton, 1951)
Sattelmacher, P. G	1962*
Saunby, T	1953*
Sawyer, C. N	1944 (See Sawyer, 1952), 1945 (Also see Anon., 1949), 1945*, 1947*, 1952*, 1954*
Schelske, C. L	1960 (See Knight and Ball, 1962)
Schmitt, K. P	1949 (See Moore, 1958)
Scott, R. H	1956 (See Mackenthun et al., 1964)
Schuette, H. A	1918*, 1928*, 1929a*, 1929b*
Shewan, J. M	1943 (See Borgstrom, 1961)
Shipman, H. R	1950
Silvey, J. K. G	1953 (See Engelbrecht and Morgan, 1959)
Sinclair, N. R	1958
Skoog, F	1950, 1952 (See Fitzgerald, 1965), 1954, 1957, 1957a
Smalley, A. E	1957 (See Odum, 1959)
Smith, E. V	1939, 1947 (See Odum, 1959)
Solimorskaja-Rodina, A. C.	1940 (See Hooper and Elliott, 1953)
Spaeth, J. P	1962
Spiegelman, S	1948

---

*Sole or Senior Author.

Starrett, W. C.	1960
Steel, J. H.	1957 (See Knight and Ball, 1962)
Steeman, N. E.	1954 (See Knight and Ball, 1962)
Stevenson, W.	1949 (See Hooper and Elliott, 1953)
Stommel, H.	1949 (See Moore, 1958)
Strickland, J. D. H.	1960 (See Knight and Ball, 1962)
Stumm, W.	1962*
Sutherland, A. K.	1950
Swingle, H. S.	1939*, 1947 (See Odum, 1959)
Sylvester, R. O.	1961*, 1963*, 1964*
Takahashi, D.	1957 (See Odum, 1959)
Tamiya, H.	1957 (See Odum, 1959), (See Knight and Ball, 1962)
Tamm, C. O.	1951*, 1953*
Tanimoto, T.	1957 (See Odum, 1959)
Tanner, H. A.	1951, 1960*
Tebo, L. B.	1955 (See Mackenthun et al., 1964)
Tucker, A.	1957*, 1957a*
Tucker, J. M.	1961*
Vaccaro, R. F.	1964*
Vallentyne, J. R.	1952*
Vanderborgh, G., Jr.	1949 (See Lackey, 1958)
Van Slyke, L. L.	1932 (See Millar, 1955)
VanVuran, J. P. J.	1948*
Verduin, J.	1956 (See Odum, 1959)
Viosca, P.	1935 (See Odum, 1959)
Voigt, G. K.	1960*
Walton, G.	1951*
Warburg, O.	1920 (See McKee, 1962)
Watanabe, A.	1951 and 1956 (See Krauss, 1958)
Weaver, J. E.	1954 (See Odum, 1959)
Webster, G. C.	1959
Weeks, O. B.	1945
Weibel, S. R.	1964*
Whipple, G. C.	1948*
Whipple, M. C.	1948
Whitford, L. A.	1959*
Wielding, S.	1941 (See Krauss, 1958)
Wiley, A. J.	1956 (See Mackenthun et al., 1964)
Wilson, S. L.	1955
Winks, W. R.	1950*
Wisniewski, T. F.	1956 (See Mackenthun et al., 1964)
Wolfe, M.	1954 (See McKee, 1962)
Woodward, R. L.	1950, 1960

---

*Sole or Senior Author.

Woytinsky, E. S	1953 (See Knight and Ball, 1962) (Also see Odum, 1959)
Woytinsky, W. S	1953 (See Knight and Ball, 1962) (Also see Odum, 1959)
Wuhrmann, K	1962 (See McGauhey et al., 1963), 1963 (See McGauhey et al., 1963)
Wurtz, A. G	1962*
Zehnder, V. A	1958 (See Fitzgerald, 1965)
Zicker, E. L	1956*
Zilversmit, D. B	1943*
Zon, R	1930 (See Donahue, 1961)

---

*Sole or Senior Author.

Introduction

In the press, around the conference table, and in the courts, thoughtful and extensive attention has been directed to the excessive enrichment of water, especially the standing water in recreational lakes and ponds. At no time in history except the present has the focus of public attention on the water enrichment problem been more acute, or more demanding that remedial measures be taken to make the water aesthetically pleasing for multiple recreational use. Such a public reaction results either from a greater awareness of a chronic situation that has existed over extended time or from recently produced, dynamically acute, or rapidly accelerating biological nuisances. Although it is well documented that many lakes throughout the country have been fertile reservoirs for algal development for many years, it is also equally obvious that the developing megalopolis and the expanding industry are pouring nutrients into the nation's waterways at an accelerating rate, and that aquatic weed growths and algal nuisances have increased in areas where before they did not exist and have magnified in areas where before there was a tolerable growth.

The scope of eutrophication or water enrichment is broad and the ramifications are many. In this book consideration has been limited principally to the nutrients, nitrogen and phosphorus, and to the role that these elements play in lake aging. The process of lake aging has been termed irreversible when measured by the clock of geologic time. When the refuse and rejectamenta of civilization are the principal accelerators of the process, corrective action can slow the eutrophication process, and perhaps temporarily revert it. Although they sometimes require great effort and expenditure of monies, localized nuisances may be abated. Even when nonnatural pollution may be substantially removed from a watercourse, many years may be required to effect a "flushing out" from the lake of those nutrients that have been recycling with the biomass therein. It is usually safe to assume that the lake will never again attain its crystal-clear, pristine appearance that has been so well imprinted on the minds and in the thoughts of long-time local residents. Unfortunately, in most instances, historic scientific evidence is not available with which to compare recent studies on a water body. Hopefully, as good data are amassed, this will be corrected in the future.

To properly assess a nutrient problem, consideration should be given all of those sources that may contribute nutrients to the watercourse. A partial list of these would include the nutrients in sewage, sewage effluents, industrial wastes, land drainage, applied fertilizers, precipitation, urban runoff, soils, and that which may be released from bottom sediments and from decomposing plankton. Nutrients contributed by transient ducks, falling tree leaves, and ground water may be important additions to the nutrient budget. Flow measurements are paramount in a study to quantitatively assess the respective amounts contributed by various sources during different seasons and at different flow characteristics. In the receiving lake or stream the quantity of nutrients contained by the standing crops of algae, aquatic vascular plants, fish, and other aquatic organisms are important considerations. A knowledge of those nutrients that are annually harvested through the fish catch, or that may be removed from the system through the emergence of insects will contribute to an understanding of the nutrient budget.

For comparative purposes it is valuable to know nutrient concentrations that have been found in various lakes and streams, the loadings to specific lakes under varying situations, and the retention in lakes and ponds. The interaction of specific chemical components in water, prescribed fertilizer application rates to land and to water, critical nutrient values required for algal blooms, vitamins required, other limiting factors, and the intercellular nitrogen and phosphorus concentrations are likewise important. Usually, it is necessary to determine that portion of the nutritive imput attributable to man-made or man-induced pollution that may be corrected as opposed to that imput that is natural in origin and, therefore, usually not correctable. A nutrient budget is used to determine the annual imput to a system, the annual outflow, and that which is retained within the water mass to recycle with the biomass or become combined with the solidified bottom sediments. Calculations can be made to determine those nutrient portions that are incorporated in the standing crops of the respective biomass components within the system. Calculations can also be made to determine the quantity of those nutrients that are in solution within respective vertical strata of the system and to predict those nutrient concentrations that will be immediately available for plant growth during the critical spring season. Retention time or "flush-out"time may also be calculated.

In this publication, recorded data have been presented on these and associated topics. A few of these data have been tabulated in the accompanying table. More could be added but the subject index presents an almost equally convenient method of comparing data and has the added advantage of keeping it more meaningful and within the context of the abstract.

Nutrient Population Equivalents

(From Mackenthun et al., 1964)

Nutrient source	Basic reference	Contribution		Population equivalent (PE per year)	
		N	P	N	P
Treated domestic contribution in sewage	Bush and Mulford, 1954 Metzler et al., 1958	6-12* (9 lb/yr) 6** lb/yr	3-4 (3 lb/yr) 2.25 lb/yr	1	1.
Domestic duck	Sanderson, 1953	2.1 lb/yr	0.9 lb/yr	0.23 to 0.35	0.3.
Wild duck	Paloumpis and Starrett, 1960	1.0 lb/yr	0.45 lb/yr	0.11 to 0.17	0.15.
Runoff—20 percent slope, corn	Eck et al., 1957	36 lb/A/yr	1.3 lb/A/yr	4.2 to 6.3/A	0.6/A.
Runoff—8 percent slope, corn	Eck et al., 1957	18 lb/A/yr	0.5 lb/A/yr	2.1 to 3.0/A	0.166/A.
Surface irrigation diversified farming	Sylvester, 1961	2.5-24.0 lb/A/yr	0.9-3.9 lb/A/yr	0.37 to 4.0/A	0.3 to 1.3/A.
Rainwater	Hutchinson, 1957	5.5 lb/A		0.6 to 0.9/A	
Killed algae (summer maximum)	Birge and Juday, 1922	15 lb/A	1.5 lb/A	1.7 to 2.5/A	0.5/A.
Killed submerged plants	Rickett, 1922	32 lb/A	3.2 lb/A	3.6 to 5.3/A	1.1/A.
Killed fish	Beard, 1926	50 lb/ton	4 lb/ton	5.6 to 8.3/ton	1.3/ton.

* Normal range of domestic sewage for 15 California communities was given as 20 to 40 mg/1 N and PO_4.

** This concentration in treated water was subtracted from the concentration in sewage to obtain domestic contribution.

If it is assumed that phosphorus is the key element in lake enrichment and that 0.015 mg/l soluble phosphorus at the beginning of the active growing season will produce subsequent nuisance algal blooms, then dilution becomes a prime factor of consideration. Assume, then, that a treated domestic waste with a soluble phosphorus concentration of 8.0 mg/l–P is discharged to a stream with a soluble phosphorus concentration of 0.006 mg/l soluble P. Since a lake is ultimately influenced by the nutrient concentrations in its inflowing waters, the 8.0 mg/l–P waste must receive greater than a 888:1 dilution with 0.006 mg/l–P water to be below the critical algal growth value.

Considered another way, the inorganic nitrogen ($NH_3-N+NO_2-N+NO_3-N$) and soluble phosphorus concentration occurring during the period of early spring growth that are believed to cause algal nuisances are 0.8 and 0.04 pound, respectively, per acre-foot of lake water. Thus, assuming a mean water depth of 15 feet, 12 pounds per acre of inorganic nitrogen and 0.6 pound per acre of soluble phosphorus available for organism utilization in early spring might be expected to stimulate troublesome nuisances. The treated domestic contribution in sewage lies between 2 to 3 pounds per capita per year. Assuming further that the soluble phosphorus within the water body could be calculated at 0.006 mg/l–P, the amount within 15 acre-feet of water would be 0.24 pound. With this amount present, the per capita contribution would be theoretically sufficient to fertilize 7 acres of water to a depth of 15 feet sufficient to produce algal nuisances. It becomes imperative that quantities of nutrients, however small, must be kept from natural watercourses.

From the standpoint of nutrient removal, harvesting the aquatic crops annually would be advantageous. The economics of present methods of harvesting and the scope of the problem, however, necessitate a critical appraisal of the benefits versus the costs. The expected standing crop of algae approaches 2 tons per acre (wet weight). Such would contain only about 15 pounds of nitrogen and 1.5 pounds of phosphorus. Submerged aquatic plants would be expected to approach at least 7 tons per acre (wet weight) and contain 32 pounds of nitrogen and 3.2 pounds of phosphorus per acre. Values may be higher under severe nuisance conditions.

Bottom-dwelling bloodworms (midge larvae) might be expected to occur in population densities of 300 pounds per acre (wet weight). If 6 percent of this population is annually lost as emerged insects outside the lake basin, this removes only ¼ pound per acre of nitrogen and possibly $\frac{1}{10}$ as much phosphorus.

The nitrogen content of fish flesh is approximately 2.5 percent (wet weight) and the phosphorus content 0.2 percent. Thus, to remove 40 pounds of fish would remove 1 pound of nitrogen, but 500 pounds of fish must be removed to harvest 1 pound of phosphorus.

Phosphorus occurs in rocks and soils primarily as calcium phosphate, $Ca_3(PO_4)_2$. Since the phosphate rock is sparingly soluble, leaching brings into solution small amounts of the phosphorus. In natural waters the element exists as secondary calcium phosphate, $CaHPO_4$, its form being determined by the pH of the water. The low concentration of phosphorus available from geologic sources is further reduced by biological systems, since the element is necessary for all life processes. Thus in waters remote from human influence, phosphorus exists in very low concentrations as the secondary phosphate ion and as organic phosphorus incorporated into biomass. Seasonal changes in plant and animal production result in cyclic utilization and release of phosphorus to the water.

The discharge of domestic sewage increases the concentration of phosphorus markedly. Organic phosphorus in the sewage and simple and complex phosphates from synthetic detergents are the principal contributions. Decomposition of the organic material, along with soluble phosphates, results in phosphorus concentrations far above the requirements for plant growth. Therefore, in most polluted waters, soluble phosphorus is abundant. This readily available form often furnishes a food supply for nuisance biological growths.

Nitrogen comes into solution in water as the result of nitrogen fixation from the air, ammonia from rain-out, organic nitrogen from decomposing plants and animals, and land drainage. In water solution the element exists as organic nitrogen, ammonium ion, nitrite ion, and nitrate ion. In the familiar nitrogen cycle, the proteinaceous material is decomposed by bacterial action, resulting in the inorganic ions, which are in turn incorporated into new cell material. The relative concentrations of the various forms of nitrogen depend upon the biological systems involved, as influenced by environmental conditions.

When untreated domestic sewage is discharged to a watercourse, organic nitrogen (proteins) and ammonia are the principal nitrogen constituents. In the water, nitrifying organisms decompose the organic materials and oxidize the ammonia to nitrite and nitrate. Since the nitrite ion is a transient form it is usually present in very low concentrations.

Treated sewage has undergone partial oxidation in the treatment process. Therefore the nitrite and nitrate forms are increased in well treated sewage, while the organic nitrogen and ammonia are reduced.

The discharge of human wastes results in an abundance of nitrogen in all forms, causing an abrupt change in the nutrient balance of the stream.

Definitions and Equivalents

cfs=cubic feet per second; cfs×448.8=gallons per minute; cfs $\times 5.4 \times 10^6$=pounds per day

g/1=grams per liter; g/1×1,000=parts per million

g/m^2=grams per square meter; g/m^2×8.922=pounds per acre

ha=hectare; ha×2.471=acres

kg=kilograms; kg×2.2=pounds

kg/ha=kilograms per hectare; kg/ha×0.8922=pounds per acre

metric tons×2,204=pounds

μg-at P/g=microgram atoms phosphorus per gram=31 parts per million phosphorus

μg-at P/l=microgram atoms phosphorus per liter=31 parts per billion phosphorus

μg/g=micrograms per gram=ppm

μg/l=micrograms per liter=ppb; μg/l$\times 10^{-3}$=parts per million

μg/m^2=micrograms per square meter; μg/m$^2 \times 8.92 \times 10^6$=pounds per acre

mg/g=milligrams per gram; mg/g$\times 10^3$=ppm

micromoles P per 100 grams×0.31=parts per million

mg/l=milligrams per liter=parts per million

mg/m^3=milligrams per cubic meter; mg/m^3×0.00272=pounds per acre-foot

mg/m^2=milligrams per square meter; mg/m^2×8,922=pounds per acre

mg %=milligrams percent=milligrams in 100 grams=1 part in 100,000 parts wet weight; mg %×0.1=ppm

mgd=million gallons per day; mgd×1.547=cubic feet per second

ppb=parts per billion

ppm=parts per million

P_2O_5=phosphorus pentoxide; P_2O_5×0.436=P

PO_4=phosphate; PO_4×0.326=P

NO_3=nitrate; NO_3×0.226=N

Parts per million×cubic feet per second×5.4=pounds per day (gallons per minute$\times 2.228 \times 10^{-3}$=cubic feet per second)

Parts per million×8.34×gallons per day$\times 10^{-6}$=pounds per day (gallons per minute×1,440=gallons per day)

As a handy reference, these definitions and equivalents are presented in a fold-out sheet at the back of this book.

Abbott, W. 1957.

Unusual Phosphorus Source for Plankton Algae. Ecology, Vol. 38, pp. 152; Water Pollution Abstracts, Vol. 30, No. 8, Abs. No. 1248.

Tests were made to find the source of phosphorus used by planktonic algae in Lake Houston, a new impounding reservoir in Texas. Chemical analyses of plankton and noncolloidal detritus from the lake were made, but no phosphorus was detected in these samples. It was observed that run-off from the watershed following rains produced a high load of colloidal clay particles in the water. Samples were taken, half of which were filtered and half still contained collodial material before being analyzed for phosphorus. Samples containing colloidal matter contained an average of 85 micrograms per liter of phosphorus in the phosphate equivalent form while the filtered samples contained only minute quantities. It was, therefore, deduced that the planktonic algae were deriving their nutritive phosphorus from complex polyphosphates or organic phosphorus compounds without the aid of dissolved phosphate equivalent intermediate stage.

Allen, M. B. 1955.

General Features of Algae Growth in Sewage Oxidation Ponds. California State Water Pollution Control Board, Sacramento, California, Publication No. 13, pp. 11–34.

The maximum yield of algae obtainable from domestic sewage in the laboratory was 1 to 2 grams dry weight per liter of sewage. The element most severely limiting algal growth in the sewages studied was nitrogen. To obtain any appreciable increase in algal production it was necessary to supplement the sewage with nitrogen as well as with carbon. The mass of algae present was determined by centrifuging the cells from a known volume of medium, transferring to a tared crucible, drying, and weighing.

Algal crops in the field are more difficult to evaluate because of uncertainty as to whether all the suspended solids should be considered as algal cells, but 0.5 gram dry weight per liter appears to be the maximum observed. *Chlorella* and *Scenedesmus* were the photosynthetic organisms most important in the functioning of the oxidation ponds. It was found that these algae did not grow on sewage in the dark and that they did not reduce the content of oxidizable matter in sewage when growing on it in the light. Their development in the oxidation ponds is thus possible only by photosynthesis, for which they use carbon dioxide produced in the oxidation of organic matter by colorless organisms.

Anderson, G. C. 1961.
Recent Changes in the Trophic Nature of Lake Washington—A Review. Algae and Metropolitan Wastes, U.S. Public Health Service, SEC TR W61–3, pp. 27–33.

Lake Washington near Seattle, Washington, a lake of 21,641 acres with a maximum depth of 214 feet, receives the treated sewage of 76,300 people; eutrophication has resulted. In 1955, ". . . for the first time, there appeared an increased growth of phytoplankton made up mainly by the blue-green alga *Oscillatoria rubescens*, a notorious indicator of pollution in many lakes." The nitrogen (N) loading on the lake was 280 pounds per acre per year in 1957: the phosphorus (P) loading was 12 pounds per acre per year. The hypolimnetic oxygen deficit has increased from 105 pounds per acre per month in 1933 to 279 pounds per acre per month in 1955. The maximum hypolimnetic concentration of phosphate (PO_4-P) reached in the deepest waters was 23 ppb in 1950, 89 ppb in 1957, and 74 ppb in 1958. The standing crop of phytoplankton as indicated by measurements of phytoplankton volume and chlorophyll measurements was 0.6 part per million by volume in 1950, 1.6 in 1955, and 4.2 in 1956.

Andrews, W. B. 1947.
The Response of Crops and Soils to Fertilizers and Manures. W. B. Andrews, State College, Mississippi, 459 pp.

In North Carolina, when adequate phosphorus and potash were used, 20 pounds of nitrogen per acre produced 32 bushels of corn, 60 pounds of nitrogen per acre produced 59 bushels, and 120 pounds of nitrogen per acre produced 72 bushels.

In the process of becoming soluble, nitrogen is converted into nitric acid which combines with important elements in the soil, such as calcium and potassium, among other elements, to form soluble compounds which are subject to leaching, thus causing the loss of these mineral elements as well as nitrogen. In Kentucky, the pounds of nitrogen leached per acre ranged from 0 to 10 for alfalfa, and 0.3 to 12.2 for bluegrass to 29 to 165 where no crop was grown.

The fertilizing elements removed in harvested crops were given as follows:

Crop	Part of crop	Yield per acre	Pounds of nitrogen	Pounds of phosphoric acid (P_2O_5)
Alfalfa	Hay	4,000 lbs.	98	25
Corn	Grain	25 bu.	24	14
	Stover	1,667 lbs.	16	5
Cotton	Lint	200 lbs.		
	Seed	360 lbs.	14	6
	Stalks	600 lbs.	10	3
Potatoes	Potato	200 bu.	43	17
	Tops		40	7
Soybeans	Hay	2,000 lbs.	60	12
	Seed	15 bu.	66	16
Tobacco	Leaves	1,000 lbs.	37	7
	Stalks	800 lbs.	17	7

Soils that have a high amount of nitrogen before being brought into cultivation maintain a higher nitrogen content under cultivation than do soils which have a low amount of nitrogen before being brought into cultivation. The average nitrogen content in soil organic matter in the surface 7 inches of 8 different soil types was 4,276 pounds per acre for virgin soil and 2,781 pounds per acre for cultivated soil for a 35 percent loss in nitrogen through cultivation. Continuous cropping of corn depleted the total nitrogen in the upper 7 inches of soil by 52 percent in the first 25 years and 5 percent in the second 25 years.

In the Southeast, 48 pounds of phosphate is generally recommended each year for continuous cotton production. Fertile soils may contain as much as 5,000 to 10,000 pounds of phosphate per acre to a depth of 6⅔ inches; however, most soils contain considerably less than 5,000 pounds. Most of the phosphorus in the soil is in a form which is not available to plants, and the rate at which phosphorus becomes available is too slow to supply the needs of crops on most soils.

The pounds of nitrogen, phosphate, and potash in 1 ton of manure was given as follows:

Animal	Pounds dry matter	Nitrogen	Phosphate	Potash
Cattle:				
Solid	322	6.4	4.2	3.2
Liquid	124	19.0	.6	18.0
Hens, solid	900	20.0	16.0	8.0
Hogs:				
Solid	370	12.0	9.2	8.8
Liquid	68	6.0	2.4	20.0
Horses:				
Solid	486	10.0	6.0	4.8
Liquid	198	24.0	Trace	30.0
Sheep:				
Solid	680	13.0	9.2	4.8
Liquid	256	23.6	.6	42.0

Normally 500 to 600 pounds of fish per acre are produced in well fertilized ponds and 100 to 200 pounds in unfertilized ponds in Alabama. The fertilizers recommended for fishing ponds by the Alabama Agricultural Experiment Station per acre of water were as follows:

40 pounds of sulfate of ammonia
60 pounds of superphosphate (16%)
5 pounds of muriate of potash
15 pounds of lime.
or
100 pounds of neutral 6-8-4
10 pounds of nitrate of soda.

Two to three fertilizer applications should be made at weekly intervals of four weeks thereafter until October. When the water becomes clear enough for the bottom of the pond to be seen through 1½ to 2 feet of water, fertilizer is needed.

Anon. 1949.
Report on Lake Mendota Studies Concerning Conditions Contributing to Occurrence of Aquatic Nuisances 1945–1947. Wisconsin Committee on Water Pollution, Madison, Wisconsin, 19 pp. (Mimeo.)

The soluble phosphorus contributions to Lake Mendota, Wisconsin, from September 1945, through August 1946, was 4,198 pounds corresponding to 0.43 pound per acre as P. The following year the contribution was 7,137 pounds or 0.76 pound per acre. Soluble phosphorus averaged 0.048 mg/l for all streams entering the lake.

The inorganic nitrogen entering Lake Mendota was 203,609 pounds corresponding to 20.8 pounds per lake acre as N. The contribution of 185,472 pounds during the second year was equivalent to 19.0 pounds per acre.

During the survey, the arbitrary definition of 500 organisms of a given species per ml as constituting an algal bloom was used with the modification that those organisms were included whose population was less than 500 but whose volume was 10,000 volumetric standard units or more. The fertilization-bloom relationship using additional data from Lackey and Sawyer (1945) was given as follows:

Lake	Inorganic nitrogen (pounds per acre per year)	Inorganic phosphorus (pounds per acre per year)	Number of algal blooms per year
Mendota	19.9	0.59	10
Monona	81	7.5	43
Waubesa	435	62.8	56
Kegonsa	162	35.9	40

Since the concentration of inorganic nitrogen in Lake Mendota varied between 0.15 and 0.58 mg/1 (N) from 1945 to 1947, and inorganic phosphorus varied from 0.008 to 0.082 mg/1 (P), it may be concluded that a drainage area that is nonurban, such as that of Lake Mendota, can supply by runoff through its drainage system sufficient nutrients to fertilize the water to the nuisance-producing level.

Lackey, J. B. and C. N. Sawyer. 1945. Plankton Productivity of certain Southeastern Wisconsin Lakes as related to Fertilization. Sewage Works Journal, Vol. 17, pp. 573–585.

Anon. 1950.
Water Supply. Progress Report of the Committee on Water Supply of the American Public Health Association. American Journal of Public Health, Vol. 40, No. 5, pp. 110–120; Water Pollution Abstracts, Vol. 23, No. 8, Abs. No. 902.

The majority of cases of methemoglobinemia are associated with water containing at least 60 mg/l nitrate nitrogen, but some rural supplies contain up to 500 mg/l without the disease occurring.

Anon. 1964.
"Breakthrough" in Poultry Manure. Compost Science, Vol. 5, No. 2, p. 30.

A British firm, Hydraulics Developments Ltd., is reported to have developed a process of drying poultry manure droppings and producing a dry sterile powder for use as a natural organic fertilizer. Ministry of Agriculture analyses of 10 samples gave an average reading of 5.3 percent nitrogen, 5.1 percent phosphate, and 2.1 percent potash.

Anon. 1964a.
Midwest Farm Handbook. The Iowa University Press, Ames, Iowa, 474 pp.

Recommendations for continuous fertilizer application to corn in the midwestern States are about 80 to 100 pounds of nitrogen per acre and 40 to 60 pounds of phosphate (P_2O_5) per acre; and to small grains, about 20 to 50 pounds of nitrogen per acre and 40 to 60 pounds of phosphate (P_2O_5) per acre. Some variation in the recommendations existed because of different soil types given consideration.

Anon. 1964b.
Activities Report, July 1, 1963–June 30, 1964. Basic and Applied Sciences Branch, Division of Water Supply and Pollution Control, Public Health Service, 57 pp.

A year's measurements of storm runoff water quality and quantity from a 27-acre residential-commercial urban area indicated annual amounts of PO_4 and total N to be 9 and 11 percent, respectively, of the estimated raw sewage content from sources on the area.

At Coshocton, Ohio, two storms with 2.21 to 5.09 inches of rainfall per storm produced a runoff of 6,600 to 76,300 gallons per acre; phosphate (PO_4) in the runoff water ranged from 0.05 to 0.42 pound per acre, and total nitrogen (N) ranged from 0.20 to 6.12 pounds per acre.

Ball, R. C. 1949.
Experimental Use of Fertilizer in the Production of Fish-Food Organisms and Fish. Michigan State College Agricultural Experiment Station Technical Bulletin No. 210, pp. 1–28.

Twenty-one ponds at three Michigan fish hatcheries were utilized in the summer of 1946 for experimental work to determine the value of fertilizers in the production of fish. Organic fertilizer in the form of barnyard manure was applied early in the spring at the rate of 1 ton to each 1½ acres of water surface. During the summer, inorganic fertilizer (10–6–4) was applied at a rate of 33.3 pounds per acre per week. The general indication was that there was a greater production of fish in fertilized water. The production of invertebrate organisms, as determined by dredge sampling, was 42 percent greater in the fertilized ponds than in the nonfertilized ponds, and the production of plankton organisms was 3.3 times greater.

Ball, R. C. 1950.
Fertilization of Natural Lakes in Michigan. Transactions American Fisheries Society, Vol. 78 (1948), pp. 145–155.

Inorganic fertilizer (10–6–4) was applied to two state-owned lakes in northern Michigan, one a 4.3-acre trout lake and the other a 27.5-acre warm-water lake. Two nearby lakes were kept under observation as controls. Fertilization was carried out at a rate of about 100 pounds per acre from June until September, 1946, and from May until August 20, 1947. Fertilizer brought about a plankton-algae bloom the first summer in the warm-water lake and produced a heavy growth of filamentous algae the second summer. No appreciable oxygen depletion occurred during the winter following the first season of fertilization. Chemical analysis in February of the second winter showed severe oxygen depletion, with oxygen levels at less than 1 mg/l at all depths. An almost complete winterkill occurred in both fertilized lakes. No winterkill occurred in the control lakes.

Ball, R. C. and H. A. Tanner. 1951.
The Biological Effects of Fertilizer on a Warm-Water Lake. Michigan State College, Agricultural Experiment Station, Tech. Bull. 223, pp. 1–32.

Inorganic fertilizer (10–6–4) was applied in the shoal areas of North Twin Lake, which comprises 27.5 acres, at a rate of 100 pounds every 3 weeks from early May until mid-September of 1946 and 1947. A definite increase in plankton followed each application of fertilizer. Heavy mats of filamentous algae appeared during the second summer and were a nuisance to fishermen, overburdened higher aquatic plants, and had an unpleasant odor as they decayed. A statistical analysis of growth rates before and during fertilization showed a highly significant increase in growth following fertilization for all major game fishes and for all ages for which data were available. An almost complete winter-kill of fish followed the second summer of fertilization.

Beard, H. R. 1926.
Nutritive Value of Fish and Shellfish. Report U.S. Commissioner of Fisheries for 1925, pp. 501–552.

The approximate nitrogen content of fish flesh is 2.5 percent (wet weight) and the phosphorus content 0.2 percent. Thus it would be necessary to harvest about 1 ton of fish to remove 50 pounds of nitrogen and 4 pounds of phosphorus; 40 pounds of fish would remove 1 pound of nitrogen and 500 pounds of fish would remove 1 pound of phosphorus.

Bennett, G. W. 1962.
Management of Artificial Lakes and Ponds. Reinhold Publishing Corporation, New York, 283 pp.

The fertilization of ponds and lakes cannot be recommended as a general fish management technique outside of the southeastern United States, because the results are too variable and uncertain. Once the fertility of small impoundments in productive soils has been built up, this fertility may manifest itself in luxuriant annual crops of filamentous algae, blue-green algae, or rooted aquatic vegetation. There are already numerous examples of such ponds, most of which are quite productive of fish; but they are problem waters because a treatment to kill rooted vegetation will be followed by obnoxious blooms of algae which in turn may require chemical treatment. These lakes have reduced aesthetic values, and fishing and swimming are limited by plant growths of one type or another. In ponds in some of the least productive soil types in Illinois the addition of recommended amounts of inorganic fertilizer increased the average standing crop of fish by only about 1.22 times. The improvement in fishing was such that uninformed fishermen could not tell which ponds were fertilized and which were not; yet in terms of total yield, rate of catch, and average size, the fertilized ponds produced considerably better bluegill fishing than did unfertilized control ponds. In contrast, the controls usually produced a higher yield of bass, 10 inches or larger, than did the fertilized ponds.

Benoit, R. J. 1955.
Relation of Phosphorus Content to Algae Blooms. Sewage and Industrial Wastes, Vol. 27, No. 11, pp. 1267–1269.

The author cites Juday and Birge (1931) as reporting a mean of 23 parts per billion total phosphorus for 479 lakes of northeastern Wisconsin, and Hutchinson (1941) as reporting a mean of 21 parts per billion total phosphorus for 23 analyses of the surface water of Linsley Pond, North Branford, Connecticut.

An attempt is made to answer questions regarding the type of phosphorus for which to analyze by a definition of terms. Total phosphorus is determined by digesting an unfiltered sample and determining the phosphate content by the molybdate method. If a filtered sample is digested, and the sample analyzed for phosphate, the total soluble phosphate is determined. The difference between total phosphate and total soluble phosphate is termed particulate phosphate. This form is not immediately suitable for algal metabolism, although all phosphate is potentially available when released into solution by the activity of bacteria.

Juday, C. and E. A. Birge. 1931. A Second Report on the Phosphorus Content of Wisconsin Lake Waters. Transactions Wisconsin Academy Sci., Arts, Letters, Vol. 26, pp. 353–382.

Hutchinson, G. E. 1941. Limnological Studies in Connecticut: IV Mechanism of Intermediary Metabolism in Stratified Lakes. Ecological Monographs, Vol. 11, pp. 21.

Benoit, R. J. and J. J. Curry. 1961.
Algae Blooms in Lake Zoar, Connecticut. Algae and Metropolitan Wastes, U.S. Public Health Service, SEC TR W61–3, pp. 18–22.

Lake Zoar was formed in 1919 by Stevenson Dam on the Housatonic River and by 1947 algae were so plentiful that a serious nuisance was created for lake-side property owners. The lake volume is estimated to be 42,800 acre-feet and the average flow of the Housatonic River at

Lake Zoar is 2,500 cfs, indicating a flow through time of 9 days. During the algal season, low monthly flows result in a replacement of the lake volume every 40 days. About 183 pounds per day of phosphorus (P) enter Lake Zoar giving rise to a concentration of 12 to 41 parts per billion in the water mass.

Birge, E. A. and C. Juday. 1922.
The Inland Lakes of Wisconsin. The Plankton. I. Its Quantity and Chemical Composition. Wisconsin Geological and Natural History Survey, Bulletin No. 64, Scientific Series No. 13, pp. 1–222.

Computations based on the area and total volume of Lake Mendota, Wisconsin, show that the largest standing crop of spring plankton yielded 360 pounds while the largest autumn crop was 324 pounds per acre. The smallest summer minimum amounted to 124 pounds per acre and the smallest winter minimum, 98 pounds per acre. The average amount of organic matter yielded by the entire series of plankton catches from Lake Mendota was 214 pounds per acre. These figures represent the weight of the dry organic matter in the plankton; the wet weight would be approximately ten times as large. In 166 analyses over a 7-year period, the minimum mean annual percentage of total nitrogen (N) varied from 3.92 to 6.60 percent (dry weight) and the maximum mean annual percentage ranged from 7.02 to 9.97 percent.

The percentages of total nitrogen (N) and phosphorus (P) on a dry weight basis are presented for a number of organisms:

Organism	Percentage of the dry weight	
	N	P
Microcystis	9. 27	0. 52
Anabaena	8. 27	. 53
Volvox	7. 61	1. 10
Cladophora	2. 77	. 14
Myriophyllum	3. 23	. 52
Cyclops	9. 57	1. 02
Limnocalanus	7. 18	. 78
Daphnia pulex	6. 55	1. 60
Daphnia pulex	8. 61	1. 54
Daphnia pulex	7. 55	1. 48
Leptodora	9. 28	1. 56
Cambarus	6. 60	1. 16
Hyalella	7. 37	1. 20
Hirudinea	11. 13	. 76
Zygoptera	10. 62	. 66
Sialis	8. 07	. 64
Chironomus tentans	7. 36	. 93

Borgstrom, G. (Editor), 1961.
Fish as Food. Academic Press, New York. 725 pp.

In fish cultivation, 30 to 50 kg. of pure phosphoric acid per hectare of water surface leads to a yield increase of about 100 kg. of fish flesh per hectare. On the basis of numerous experiments, it may be expected that 1 kg. of phosphoric acid will render an additional yield of 2.1 kg. of fish flesh.

In general, the protein content is calculated by multiplying the amount of nitrogen with the coefficient 6.25 although there is disagreement on the specific coefficient. Protein nitrogen is by far the most important nitrogen fraction. The distribution of nitrogen in fish flesh was given as follows:

Species	Total N (%)	Protein N (%)	Reference
Cod, Atlantic	2.83	2.47	Reay et al. (1943).
Herring, Atlantic	2.90	2.53	Boury (1936).
Sardine	3.46	2.97	Boury (1936).
Haddock	2.85	2.47	Reay et al. (1943).
Lobster	2.72	2.04	Campbell (1935).

The reported acid-soluble total phosphorus of the fish muscle ranged from 5,670 to 15,300 micromoles per 100 grams (approximately 1,814 to 4,896 parts per million wet weight or 0.18 to 0.49 percent; 200 to 600 pounds of fish would contain 1 pound of phosphorus).

Boury, M., 1936. Recherches sur l'alteration du poisson. Rev. trav. office pêches maritimes, Vol. 9, pp 401–419.

Campbell, J., 1935. The non-protein nitrogenous constituents of fish and lobster muscle. J. Biol. Board Can., Vol. 1, pp 179–189.

Reay, G. A., C. L. Cutting, and J. M. Shewan, 1943. The Nation's Food. VI. Fish as Food. II. The Chemical Composition of Fish. J. Soc. Chem. Ind., Vol. 62, pp 77–85.

Bosch, H. M.; A. B. Rosenfield; H. R. Shipman, and F. L. Woodward. 1950.
Methemoglobinemia and Minnesota Well Supplies. Journal American Water Works Association, Vol. 42, pp. 161–170; Water Pollution Abstracts, Vol. 23, No. 11, Abs. No. 1283.

Because 139 cases of cyanosis of infants had occurred in Minnesota since 1947 an investigation was made of well water supplies throughout the state. Of the 125 dug wells and 4 drilled wells examined as having been directly concerned in cases of the illness, none contained less than 10 mg/l nitrate nitrogen (NO_3-N) and only 2 contained as little as 10 to 20 mg/l. The average concentration of nitrate nitrogen (NO_3-N) in all the wells suspected of being responsible for the development of methemoglobinemia was 102 mg/l. None of the wells reached the standards for safe water supplies specified by the Minnesota Department of Health. Five hundred and fourteen municipal supplies were examined throughout the state; of these 5.4 percent contained over 5 mg/l nitrate nitrogen, 3.1 percent contained 10 mg/l or more, and the highest concentration determined was 27 mg/l found in a dug well in a section of the state from which most of the cases of methemoglobinemia had been reported.

Burkholder, P. 1929.
Biological Significance of the Chemical Analyses. *In:* Preliminary Report on the Cooperative Survey of Lake Erie, Season of 1928. Bulletin Buffalo Society of Natural Science, Vol. 14, No. 3, pp. 56–72. [From Putnam and Olson, 1959]

Greatest concentration of ammonia was found at the surface of Lake Erie in September (0.038 mg/l). At the bottom depth of 17 meters, there was 0.08 mg/l. Average for all stations showed a marked increase in ammonia content of the upper strata as the season advanced; in July it was 0.014 mg/l, in August, 0.015 mg/l, in September, 0.03 mg/l. Nitrates were more abundant than other forms of nitrogen. The greatest amount was found at intermediate depths in July when the value reached 0.20 mg/l. An average for all stations was 0.15 mg/l in July, 0.123 mg/l in August, and 0.137 mg/l in September.

Burkholder, P. R. and L. M. Burkholder. 1956.
Vitamin B_{12} in Suspended Solids and Marsh Muds Collected Along the Coast of Georgia. Limnology and Oceanography, Vol. 1, No. 3, pp. 202–208.

The vitamin B_{12} content of suspended solids in river and sea waters and in marsh muds, collected along the coast of Georgia, was determined by means of the *E. coli* mutant assay. Appreciable amounts of vitamin B_{12} are carried on suspended particles of river water, the brown water types showing highest concentrations, up to 6.4 μg per gram of solids. Vitamin B_{12} content of particulate matter in the sea waters varied over the range 0.0027 to 0.130 μg per liter. Calculated in relation to dried solids, the highest concentration of B_{12} was 0.736 μg per gram of solids. It was concluded that suspended particles are important in the vitamin nutrition of the sea and that bacteria are significant producers and carriers of vitamin B_{12} in the marine environment.

Campbell, W. A. B. 1952.
Methemoglobinemia due to Nitrates in Well Water. British Medical Journal, Vol. 2, pp. 371–373.

Cases of infantile nitrate poisoning have been reported to arise from concentrations ranging from 15 to 250 mg/l nitrate nitrogen (NO_3-N).

Chalupa, J. 1960.
Eutrophication of Reservoirs by Atmospheric Phosphorus. Sci. Pap. Inst. Chem. Technol., Prague, Fac. Technol. Fuel. Wat., Vol. 4, Pt. I, pp 295–308 (English summary); Water Pollution Abstracts, Vol. 35, No. 5, Abs. No. 660.

Data collected over a 7-month period in 1958–59 at the Sedlice Reservoir, Czechoslovakia, show that the whole reservoir (35.8 ha) received about ¾ kg. of inorganic phosphorus (as P_2O_5) from the atmosphere. This source of phosphorus is important in stimulating primary production of organisms in the trophogenic zone during periods of normal thermal stratification when the penetration of inorganic phosphorus from the bottom layers cannot satisfy the demand of developing organisms in the surface layers.

Chandler, D. C. and O. B. Weeks. 1945.
Limnological Studies of Western Lake Erie. V. Relation of Limnological and Meteorological Conditions to the Production of Phytoplankton in 1942. Ecological Monographs, Vol. 15, pp. 436–456. [From Putnam and Olson, 1959]

All analyses were made on composite samples prepared from surface samples and from samples at 5 and 9 meter depths. All analyses were completed within 6 hours of the time of collection.

Organic nitrogen varied from a high of 26 micrograms per liter on August 26 to a low of 2 micrograms per liter on September 18; these extremes coincided with a high and low level of phytoplankton, respectively.

Soluble phosphate phosphorus values varied from 1 to 8 micrograms per liter with the high point occurring at three times: (1) at the time of greatest organic phosphorus concentration, (2) during a period of increased turbidity which apparently resulted from increased river discharge, and (3) two weeks following the cessation of the autumn phytoplankton pulse. Lowest values occurred when the phytoplankton population was decreasing. Twenty-nine percent of the total phosphorus content was in the soluble phosphate phosphorus state.

Nitrate nitrogen varied from 0 to 1,400 micrograms per liter, ammonia nitrogen from 8 to 120 micrograms per liter, and nitrite nitrogen from 0 to 38 micrograms per liter.

Chu, S. P. 1942.
The Influence of the Mineral Composition of the Medium on the Growth of Planktonic Algae. Part I. Methods and Culture Media. Journal of Ecology, Vol. 30, No. 2, pp. 284–325.

With few exceptions the planktonic algae investigated grow equally well in media supplied with nitrate and in those supplied with ammonium salts as long as the N concentration is within the optimum range, but in lower N concentrations growth is generally better when nitrate is supplied. The requirements of N and P agree well among the different planktonic algae, although there are minor differences in the upper and lower limits that are suitable. All of the algae studied flourished in media with N ranging from 1 to 7 and P from 0.1 to 2 mg/1 respectively. The algae are likely to suffer from a deficiency when the concentration of N is below 0.2 mg/1 and that of P below 0.05 mg/1 and from an inhibiting effect when the concentration of N and P exceed 20 mg/1. The optimum range of P concentration is often wider when nitrate is used than when ammonium salt is used as the source of N.

Chu, S. P. 1943.
The Influence of the Mineral Composition of the Medium on the Growth of Planktonic Algae. Part II. The Influence of the Concentration of Inorganic Nitrogen and Phosphate Phosphorus. Journal of Ecology, Vol. 31, No. 2, pp. 109–148.

The upper limit of concentrations of nitrogen and phosphorus for optimum growth of the plankton organisms studied is always higher than the highest concentrations occurring in ordinary waters, so that their growth is unlikely ever to be unfavorably affected by too high a concentration of nitrogen or phosphorus. On the other hand, the concentration of nitrogen and phosphorus in nearly all natural waters frequently falls below, or in some never reaches, the lower limits for optimum growth. The lower limit of the optimum range of nitrogen concentration differs for different organisms. It generally varies approximately from 0.3 to 1.3 and sometimes to 2.6 or 5.3 mg/l when an ammonium salt is the source of nitrogen; and from 0.3 to 0.9 mg/l when nitrate is the source of nitrogen. Below these limits the growth rate decreases with decreasing concentration of nitrogen. The upper limit of the optimum range of nitrogen concentration varies approximately from 5.3 to 13 mg/l when an ammonium salt is the source of nitrogen, and from 3.5 to 17 mg/l when nitrate is the source of nitrogen. Beyond these limits there is an increasing inhibiting effect. Optimum growth of all organisms studied can be obtained in nitrate-nitrogen concentrations from 0.9 to 3.5 mg/l and phosphorus concentrations from 0.09 to 1.8 mg/l, while a limiting effect on all organisms will occur in nitrogen concentrations from 0.1 mg/l downward and in phosphorus concentrations from 0.009 mg/l downward.

The lower limit of optimum range of phosphorus concentration varies from about 0.018 to about 0.09 mg/l; and the upper limit from 8.9 to 17.8 mg/l when nitrate is the source of nitrogen, while it lies at about 17.8 for all the planktons studied when ammonium is the source of nitrogen. Low phosphorus concentrations may, therefore, like low nitrogen concentrations, exert a selective limiting influence on a phytoplankton population. The nitrogen concentration determines to a large extent the amount of chlorophyll formed. Nitrogen concentrations beyond the optimum range inhibit the formation of chlorophyll in green algae.

Comly, H. H. 1945.
Cyanosis in Infants Caused by Nitrates in Well Water. Journal American Medical Association, Vol. 129, pp. 112–116.

The causative factor producing serious blood changes (methemoglobinemia) in infants was first reported in 1945 in polluted water containing 140 mg/l nitrate nitrogen (NO_3-N) and 0.4 mg/l nitrite (NO_2) ion in one case; in the second case, 90 mg/l nitrate nitrogen and 1.3 mg/l nitrite ion.

Cook, B. B. 1962.
The Nutritive Value of Waste-Grown Algae. American Journal of Public Health, Vol. 52, No. 2, pp. 243–251.

The proximate analysis and amounts of calcium, phosphorus, iron, carotene, ascorbic acid, and eight B-vitamins have been determined in single-celled algae grown in symbiosis with bacteria in open, outdoor ponds, on sewage and organic wastes. Dried *Scenedesmus quadricauda* and *Chlorella* were found to contain 40 to 50 percent protein and extremely large amounts of minerals. Compared with beef on a weight basis, the algae contained more of all the B-vitamins, except B_{12}, than did beef. Because of the unpleasant odor and flavor of the algae, it would be extremely improbable that it would be eaten unless effectively masked with other foods in combination.

Curl, H., Jr. 1959.
The Origin and Distribution of Phosphorus in Western Lake Erie. Limnology and Oceanography, Vol. 4, No. 1, pp. 66–76.

The phosphate phosphorus distribution in western Lake Erie in May 1951 and the average concentration throughout 1950–1951 were shown to be a result of the drift current pattern and the discharge of the Maumee and Detroit Rivers. The bedrock in the lake appears to provide negligible quantities. The Detroit River supplies 405 metric tons per year at an average concentration of 2.6 μg PO_4-P/l, and the Maumee River supplies 125 tons per year at a concentration of 16 μg PO_4-P/l. There is a loss of soluble phosphorus, possibly as precipitating ferric phosphate and by adsorption onto ferric hydroxide. The bottom sediments contained an average of 56.9 mg P/g of dried mud.

"Maumee River water averaged 50 μg Fe^{+++}/l in 1950–51, which could be present as hydroxide or as ferric phosphate. In the latter state 50 μg of iron would be combined stoichiometrically with 27 μg of phosphorus. In an excess of ferrous ion, ferric hydroxide could be adsorbed onto the colloid, and the complex would then precipitate. A mechanism such as this would account for the high phosphorus values of the lake sediments. If 27 μg of the average of 43 μg PO_4-P/l in Maumee River water were to be combined as ferric phosphate and lost by precipitation to the river and estuary bed, 16 μg would remain."

Phosphate phosphorus and turbidity in the lake are positively correlated and evidence from turbidity data indicates that the lake is enriched by a thin-layered tongue of water from the south shore streams which flows over or under the clearer, nutrient-poor water, and then mixes vertically with it.

Removal of fish by man accounts for an annual loss of 29 metric tons, or 6 percent of the average annual input. Approximately 94 metric tons may be held temporarily as phytoplankton. The density of the diatom cells was taken as 1.1 and the average wet weight as organic matter of freshwater and marine phytoplankton had been found to be 5 percent.

Curry, J. J. and S. L. Wilson. 1955.
Effects of Sewage-borne Phosphorus on Algae. Sewage and Industrial Wastes, Vol. 27, No. 11, pp. 1262–1266.

Since the formation of Lake Zoar on the Housatonic River in Connecticut by the construction of the Stevenson Dam, the number of algae and aquatic weeds in the lake have increased considerably, and a study of the problem was carried out in 1954. Phosphorus concentrations in the lake varied from 12 to 41 ppb and averaged about 25 ppb.

Preliminary studies using 200 mg/l alum in 4,000-gallon batch treatments with a mixing time of 10 minutes and a settling time of 2 hours treating sewage plant effluents having a phosphorus content of 3.61 to 4.62 mg/l gave 96.7 percent removal of phosphates.

Deevey, E. S., Jr. 1940.
Limnological Studies in Connecticut. V. A Contribution to Regional Limnology. American Journal of Science, Vol. 238, pp. 717–741.

Examination of 49 lakes in Connecticut and New York provided data showing a close relationship between the geology of the region and the quantity of phytoplankton in the lakes. Lakes overlying soluble sedimentary rocks, rich in iron, had abundant phytoplankton and a high phosphorus concentration; those surrounded by metamorphic rock were poor in phytoplankton. In order of importance in the control of phytoplankton growth was phosphorus first, followed by nitrogen.

Lakes of Connecticut resemble those of northeastern Wisconsin with respect to the amounts of soluble and total phosphorus. The lakes in both regions "live beyond their means" with regard to their phosphorus content; under arctic conditions, the phosphorus oligotype would result in oligotrophy.

Domogalla, B. P. and E. B. Fred. 1926.
Ammonia and Nitrate Studies of Lakes Near Madison, Wisconsin. Journal of the American Society of Agronomy, Vol. 18, pp. 897–911.

Surface and bottom samples of 2 to 5 liters taken each two weeks were analyzed for organic nitrogen, ammonia nitrogen, nitrate nitrogen, and phosphate phosphorus.

Of the five lakes examined, the water of Lake Waubesa (Madison, Wisconsin) showed a consistently higher organic nitrogen content than did the others and, also, the greatest concentration of phytoplankton. The range was 980 mg per cubic meter in June to 1,470 mg per cubic meter in the latter part of August.

In all the lakes, ammonia concentration increased during March and April but began to decrease with the increase in plankton concentration.

The nitrate changes followed the same variation as organic nitrogen and ammonia. Concentration of phosphate phosphorus decreased with increasing concentration of plankton.

Analysis of lake water following heavy rains showed a marked increase in the concentration of soluble phosphorus and the different forms of nitrogen.

Domogalla, B. P., E. B. Fred, and W. H. Peterson. 1926a.
Seasonal Variation in the Ammonia and Nitrate Content of Lake Waters. Journal American Water Works Association, Vol. 15, pp. 369–385. [From Putnam and Olson, 1959]

In Lake Mendota, Wisconsin, beginning with the fall overturn, there was little change in soluble nitrogen until February and March; by the time the spring overturn occurred in April, there was an increase of 300 percent in free ammonia and 200 percent in nitrate nitrogen in the bottom levels.

In Lake Michigan, at the surface, the concentration of ammonia was 102 mg per cubic meter; nitrate was 50 mg per cu. m. At 72 meters depth, ammonia was 204 mg per cu. m.; nitrate was 79 mg per cu. m.

Domogalla, B. P., C. Juday, and W. H. Peterson. 1925.
The Forms of Nitrogen Found in Certain Lake Waters. Journal of Biological Chemistry, Vol. 63, pp. 269–285. [From Putnam and Olson, 1959]

Lake Mendota, Wisconsin, contained more than 9 times as much soluble nitrogen as it did total plankton nitrogen. Ammonia nitrogen varied from 11.6 to 39.2 mg. per cu. m. during a 1-year period. Most of the soluble nitrogen was formed at the bottom of the lake, spreading upward toward the surface. At the spring and fall overturns, the soluble nitrogen content of the lake was uniform. As soon as stratification occurs, the concentration of soluble nitrogen in the hypolimnion exceeds that in the epilimnion.

Donahue, R. L. 1961.
Our Soils and Their Management. The Interstate Printers and Publishers, Inc., Danville, Illinois, 568 pp.

Nitrogen in representative surface soils varies from 0.2 percent in the sandy soils of Florida and Virginia to approximately 0.15 percent in a limestone soil in the Lake States. The amount of nitrogen in a soil is proportional to the amount of organic matter. The percentage of nitrogen multiplied by 20 usually equals the percentage of organic matter. Phosphorus varies from a trace to 0.3 percent in surface soils. Nitrogen and phosphate in a productive soil average about 0.1 pound per cubic foot each.

The pounds of plant nutrients required per acre for good acre yields were given as follows:

	Nutrients per acre		
	Pine trees (annual growth)	Corn (100 bushels)	Alfalfa (6 tons)
Nitrogen (*N*)	24	160	300
Phosphate (P_2O_5)	4	55	75
Boron		0.15	0.7

As a general rule, 1 ton of livestock, regardless of kind, will void about 1 ton per month of excrement based on an equivalent water content of 65 percent. The average composition in pounds per ton of fresh animal manures was given as follows:

	Nitrogen(*N*) (pounds)	Phosphate (P_2O_5) (pounds)
Cattle	10	4
Horses	13	5
Hogs	10	7
Sheep	21	8
Poultry	20	16

Sawdust contains 4 lbs N and 2 lbs P_2O_5 per ton of dry material: wheat straw 10 and 3 pounds, respectively; alfalfa hay, 48 and 10.

Activated sewage sludge contains 5.6 percent nitrogen (N) and 5.7 percent phosphorus (P_2O_5); digested sludge, 2.4 and 2.7 percent respectively.

The pounds of fertilizer recommended per acre per year on grassland varies from 50 in the Pacific and Great Plains regions to 450 pounds in the northeast and southeast. The percentage of the recommended amount that is applied varies from 0.8 to 16 percent in the above named regions.

On the average 3,500 pounds of tree leaves per acre, on the oven-dry basis, fall to the ground each year (Metz, 1954). This compares with approximately 1,700 pounds from jack pines and red pine stands in Minnesota (Alway and Zon, 1930) and between 3,000 and 4,000 pounds from New England red pine forests (Lunt, 1948). The nutrients returned annually to the soil by forest tree leaves were cited as follows (Chandler 1941 and 1943):

	Pounds per acre returned annually	
	Nitrogen	Phosphorus
Conifer	23.6	1.8
Hardwood	16.6	2.3

Metz, L. J., 1954. Forest Floor of South Carolina Piedmont Stands. Soil Sci. Soc. Amer. Proc.

Alway, F. J. and R. Zon, 1930. Quantity and Nutrient Content of Pine Leaf Litter. Journ. Forestry, Vol. 28, pp. 715–727.

Lunt, H. A., 1948. The Forest Soils of Connecticut. Connecticut Agr. Exp. Station Bul. No. 523.

Chandler, R. F., Jr., 1941. The Amount and Nutrient Content of Freshly Fallen Leaf Litter in the Hardwood Forests of Central New York. Journ. Amer. Soc. Agron., Vol. 33.

Chandler, R. F., Jr., 1943. Amount and Mineral Nutrient Content of Freshly Fallen Needle Litter of Some Northeastern Conifers. Soil Sci. Soc. Amer. Proc., Vol. 8.

Douglas, J. S. 1959.
Hydroponics
Oxford University Press, London, 144 pp.

The dry fertilizer salts, which are used in hydroponics, go into solution with the water present in the beds of aggregate forming a liquid plant food. A suitable nutrient solution would contain:

Element	Mg./l.	Element	Mg./l.
Nitrogen	200 to 400	Iron	2 to 10
Potassium	100 to 200	Manganese	0.5 to 5
Phosphorus	80 to 100	Boron	0.5 to 5
Magnesium	50 to 100	Copper	0.5
Calcium	300 to 500	Zinc	1.0

Variations of these concentrations have been used with success, and much depends on locality, climate, and light conditions.

Dugdale, V. A. and R. C. Dugdale. 1962.
Nitrogen Metabolism in Lakes. II. Role of Nitrogen Fixation in Sanctuary Lake, Pennsylvania. Limnology and Oceanography, Vol. 7, No. 2, pp. 170–177.

A study of the rates of nitrogen fixation using N^{15} as a tracer was made in Sanctuary Lake, Pennsylvania. The rates of fixation in the lake were found to be considerable (at least 1 percent per day of the organic or "reduced" nitrogen already present at the beginning of the experiment) during the summer and appeared to be correlated with the presence of a dense population of *Anabaena*. Laboratory experiments supported the idea that photosynthetic organisms were responsible since a strong correlation with light was found.

Dugdale, V. A. and R. C. Dugdale. 1965.
Nitrogen Metabolism in Lakes. III. Tracer Studies of the Assimilation of Inorganic Nitrogen Sources. Limnology and Oceanography, Vol. 10, No. 1, pp. 53–57.

The activity of the phytoplankton in Sanctuary Lake, Pennsylvania, was found to fall in three clearly defined periods: (1) a spring bloom when NH_3-N, NO_3-N, and N_2-N are assimilated strongly and in that order of importance; (2) a midsummer period when weak assimilation of NH_3-N and N_2-N, but not NO_3-N, occurred; and (3) a fall bloom with intense nitrogen fixation and some NH_3-N uptake, but characterized by low NO_3-N activity. Nitrogen fixation and NH_3-N uptake appear to proceed concurrently, although ammonia uptake dominates in spring and nitrogen fixation dominates in fall.

Dugdale, R. C., J. J. Goering, and J. H. Ryther. 1964.
High Nitrogen Fixation Rates in the Sargasso Sea and the Arabian Sea. Limnology and Oceanography, Vol. 9, No. 4, pp. 507–510.

Nitrogen fixation rates were measured in the Sargasso Sea and the Arabian Sea using the N^{15} method. It was considered a virtual certainty that the large-scale blooms of *Trichodesmium* from tropical oceanic regions were nitrogen-fixing blooms analogous to those observed in lakes associated with several species of *Anabaena*. The ability to fix nitrogen was clearly shown to lie with the *Trichodesmium* colonies (that is, the alga and any associated bacteria or fungi).

Dugdale, R. C. and J. C. Neess. 1961.
Recent Observations on Nitrogen Fixation in Blue-Green Algae. Algae and Metropolitan Wastes, U.S. Public Health Service, SEC TR W61–3, pp. 103–106.

The authors cite necessary conditions for intense nitrogen fixation: (1) the general physical and nutritional characteristics of the body of water must be such as to encourage the growth of blue-green algae,

(2) some factor(s) must operate to reduce the concentrations of the various forms of combined nitrogen to very low levels, (3) an adequate supply of phosphorus would appear to be critical, and (4) certain elements (calcium, boron, and molybdenum) in trace amounts are known to be specifically necessary to permit nitrogen fixation by particular species of blue-green algae. Dilute sea-water is a reasonably good medium for nitrogen-fixing blue-green algae, perhaps because it contains favorable amounts of trace elements. It seems possible that some of these elements are concentrated in sewage, resulting under certain circumstances in the stimulation of nitrogen fixation by this material.

Engelbrecht, R. S. and J. J. Morgan. 1959.
Studies on the Occurrence and Degradation of Condensed Phosphate in Surface Waters. Sewage and Industrial Wastes. Vol. 31, No. 4, pp. 458–478.

Rudolfs (1947) reported an average phosphate concentration in raw sewage of 5.2 mg/1 as P_2O_5. The average concentration in effluents from biological treatment was 0.5 mg/1 as P_2O_5. Rudolfs indicated that per capita phosphate contributions from domestic raw sewage were from 3.3×10^{-3} to 7.5×10^{-3} lb/day as P_2O_5. Sawyer (1952) calculated that the contribution of phosphates used in the detergent and water softening industry during 1950 amounted to 10×10^{-3} lb/day/cap as P_2O_5. Estimates by the Association of American Soap and Glycerine Producers indicated a synthetic detergent consumption of 16 lb/cap for the year 1955. This corresponded to a contribution of 12×10^{-3} lb/day/cap as P_2O_5 to sewage by household synthetic detergents alone. Sawyer (1944) reported total phosphorus land drainage of approximately 1.6 lb/day sq mile, of which approximately 75 percent was organic. Silvey (1953) observed that organic phosphorus in plant leaves may be oxidized to soluble phosphates. Sudden additions of water through rainfall could wash phosphates to the stream. Dietz and Harmeson (1958) concluded that the average total phosphate concentration in Illinois surface waters was 0.648 mg/1 as P_2O_5. Solely on the basis of stream analysis data, they estimated that the phosphate contribution from domestic sewage would range from 7.07×10^{-3} to 87.3×10^{-3} lb/day/cap.

Results from 9 samples collected at 8 lake and reservoir sources believed to be relatively free of domestic pollution gave a mean orthophosphate concentration of 0.036 mg/1 P_2O_5 and a mean value of orthophosphate plus the maximum inorganic condensed (hydrolyzable) P_2O_5 of 0.081 mg/1.

The analytical results from 27 samples from streams in the major Illinois River basin suspected to contain significant amounts of treated and untreated wastes gave an average orthophosphate concentration of 0.411 mg/l P_2O_5 and an average orthophosphate plus maximum inorganic condensed P_2O_5 of 0.657 mg/1.

The mean orthophosphate concentration among 3 trickling filter sewage treatment plant effluents and 1 activated sludge plant effluent in Illinois in 1956 ranged from 11.6 to 24.2 mg/1 P_2O_5 and the per capita contributions from 9.4 to 24.2×10^{-3} pounds per day. In addition, the maximum inorganic condensed P_2O_5 concentration ranged from 0.8 to 2.1 mg/1 and the per capita contribution from 0.7 to 2.25×10^{-3} pound per day.

Rudolfs, W. 1947. Phosphates in Sewage and Sludge Treatment. I. Quantities of Phosphates. Sewage Works Journal, Vol. 19, No. 1, pp. 43.

Sawyer, C. N. 1952. Some New Aspects of Phosphates in Relation to Lake Fertilization. Sewage and Industrial Wastes, Vol. 24, No. 6, pp 768–776.

Sawyer, C. N. 1947. Fertilization of Lakes by Agricultural and Urban Drainage. Jour. New England Water Works Assn., Vol. 61, No. 2, pp. 109–127.

Silvey, J. K. G. 1953. Relation of Irrigation to Taste and Odors. Journal American Water Works Assoc., Vol. 45, No. 11, pp. 1179.

Dietz, J. C. and R. H. Harmeson. 1958. Phosphate Compounds Occurring in Illinois Surface Waters. Proceedings 12th Indiana Waste Conference, Purdue University, Vol. 94, pp. 285.

Engelbrecht, R. S. and J. J. Morgan. 1961.
Land Drainage as a Source of Phosphorus in Illinois Surface Waters. Algae and Metropolitan Wastes, U.S. Public Health Service, SEC TR W61–3, pp. 74–79.

Phosphorus carried to surface waters may be in the simple orthophosphate form or as a soluble hydrolyzable phosphate, or it may be adsorbed on clay particles. As adsorbed forms of phosphate increase in amount their solubility in water increases rapidly. Results are reported for 100 samples from the Kaskaskia River basin that has farm lands containing 40 to 50 pounds of available P_2O_5 per acre, and are drained by tile drains. High rainfalls and high rates of percolation exist. At one station that receives no domestic sewage and receives runoff from a cultivated drainage area of 11 square miles, ortho plus hydrolyzable P_2O_5 averaged 0.1 pound of P_2O_5 per day per square mile of drainage area. For the 100 samples, the calculated pounds of P_2O_5 per day per square mile varied from 0 to 58 for ortho plus hydrolyzable with a mean of 1.4. The amount of agricultural phosphate transported to streams undoubtedly depends upon the: nature and amount of phosphates in the soil, mode of drainage, topography, intensity and distribution of rainfall, rates of infiltration and percolation, and probably other factors.

Fippin, E. O. 1945.
Plant Nutrient Losses in Silt and Water in the Tennessee River System. Soil Science, Vol. 60, pp. 223–239.

The average loss of plant nutrients per acre of row crops in Tennessee River System for the year 1939 was: 84.6 pounds of calcium, 97.9 pounds of magnesium, 212.2 pounds of potassium, 13.0 pounds of phosphorus (all expressed as oxides) and 23.8 pounds of nitrogen.

Fitzgerald, G. P. 1965. Personal Communication.

The following data were supplied:

A. *Concentration of Salts Used in Algal Media at University of Wisconsin (mg./l.)*

Salt	Gerloff's [1]	ASM [2]	Gorham's [3]	Allen's [4]	Myers' [5]
NH_4Cl	—	—	—	50	—
$NaNO_3$	124	85	496	1,000	—
KNO_3	—	—	—	—	1,210
KH_2PO_4	—	—	—	—	1,230
K_2HPO_4	10	17.4	39	250	—
$MgCl_2$	—	19	—	—	—
$MgSO_4 \cdot 7H_2O$	25	49	75	513	2,460
$CaCl_2 \cdot 2H_2O$	36	14.7	36	66	—
Fe Citrate	3	—	6	—	—
$FeCl_3$	—	.32	—	3	—
$Fe_2(SO_4)_3$	—	—	—	—	52
$Na_2SiO_3 \cdot 9H_2O$	58	—	58	—	—
Na_2CO_3	20	—	20	—	—
Citric acid	3	—	6	—	—
Na citrate	—	—	—	—	196
EDTA	—	7.4	1	—	—

B. *Concentration of Essential Ions in Media (mg./l.)*

Ions	Gerloff's	ASM	Gorham's	Allen's	Myers'
N	20	14	82	178	168
P	1.8	3.1	7	45	295
Fe	.5	.1	1	1	15
Mg	2.4	9.6	7	50	243
Ca	10	4.0	10	18	—
S	3.2	6.4	10	67	323
K	4.5	7.8	17	112	353

[1] Fitzgerald, G. P., G. C. Gerloff, and F. Skoog, Studies on Chemicals with Selective Toxicity to Blue-green Algae, Sew. and Ind. Wastes, *24:* 888–896 (1952).
[2] McLachlan, J. and P. R. Gorham, Growth of *Microcystis aeruginosa* Kutz in a precipitate-free medium buffered with tris. Can. J. Microbiol., *7:* 869–882 (1961).
[3] Hughes, E. O., P. R. Gorham, U. A. Zehnder, Toxicity of a unialgal culture of *Microcystis aeruginosa*, Can. J. Microbiol., *4:* 225–236 (1958).
[4] Allen, M. B., The Cultivation of Myxophyceae. Arch. Mikrobiol., *17:* 34–53 (1952).
[5] Burlew, J. S., Ed., *Algal Culture: From Laboratory to Pilot Plant.* Carnegie Inst. Wash., Pub. No. 600 (1953).

Flaigg, N. G. and G. W. Reid. 1954.
Effects of Nitrogenous Compounds on Stream Conditions. Sewage and Industrial Wastes, Vol. 26, No. 9, pp. 1145–1154.

In laboratory experiments to determine which forms of nitrogen were most readily utilized by microorganisms, concentrations up to about 15 mg/l showed no significant difference in the utilization of the three inorganic forms (nitrite, nitrate, and ammonia). Phosphorus was supplied by a solution of dibasic potassium phosphate. With higher concentrations of nitrogen, growth of algae was accelerated and in practice this would tend to concentrate the organisms in a shorter stretch of the stream.

Gerloff, G. C., G. P. Fitzgerald, and F. Skoog, 1950.
The Isolation, Purification, and Nutrient Solution Requirements of Blue-green Algae. Symposium on the Culturing of Algae, Charles F. Kettering Foundation, Dayton, Ohio, pp. 27–44.

The composition of basic culture solutions used for mineral nutrition experiments with *Coccochloris Peniocystis* were given as follows:

Compound	Grams per liter	PPM of essential elements
$NaNO_3$	0.0413	N 6.8
Na_2HPO_4	.0082	P 1.8
KCl	.0086	K 4.5
$MgCl_2 \cdot 6H_2O$	.0209	Mg 2.5
Na_2SO_4	.0146	S 3.3
$CaCl_2 \cdot 2H_2O$	.0359	Ca 9.8
Ferric citrate	.003	Fe .56
Citric acid	.003	
Na_2CO_3	.02	
Na_2SiO_3	.025	

Hoagland's A to Z solution is added to the culture solution at 1/25 the strength specified for higher plants.

The minimum concentration of each element for the optimum growth of *Coccochloris Peniocystis* would have the following composition in ppm: nitrogen, 13.6; phosphorus, 0.45; sullfur, 0.83; potassium, 2.25; magnesium, 0.13; iron, 0.03; and only traces of calcium derived from the inoculum and from impurities in the nutrients.

Gerloff, G. C. and F. Skoog. 1954.
Cell Content of Nitrogen and Phosphorus as a Measure of their Availability for Growth of *Microcystis aeruginosa*. Ecology, Vol. 35, No. 3, pp. 348–353.

The estimation of nutrient supplies by analysis of water collected from the area in which the algae are present may be of little value because the total supply of a nutrient element is dependent on the total volume as well as the concentration of the solution from which it is absorbed. This effective volume will vary with the extent to which the algae are moved about and come in contact with different volumes of water. The concentration of nutrients in the water may reflect only the level reached as a result of continuous withdrawal by organisms and renewal by inflow and release from less available forms. In laboratory experiments, maximum algal yields were associated with a cell content of 4.0 percent total N although a maximum cell content of 7.7 percent N was found when more nitrogen was available in the culture with no yield increase. The increase in nitrogen content of the cells represents luxury consumption. Likewise, the critical level for maximum growth was associated with a phosphorus content in the cell of 0.12 percent P and luxury consumption raised the P value to 0.46 percent with no yield increase. The mean total nitrogen (N) and total phosphorus (P) contents of seven samples of *Microcystis aeruginosa* collected from heavy algal blooms in three lakes in the vicinity of Madison, Wisconsin, was 6.83 and 0.69 percent dry weight, respectively.

Gerloff, G. C. and F. Skoog. 1957.
Nitrogen as a Limiting Factor for the Growth of *Microcystis aeruginosa* in Southern Wisconsin Lakes. Ecology, Vol. 38, No. 4, pp. 556–561.

Laboratory experiments in which nitrogen, phosphorus or iron was added to lake water singly and in combinations and the resultant algal growth determined indicated that only nitrogen, phosphorus, and iron need be considered possible limiting elements. Of these, nitrogen is much more critical than either phosphorus or iron. Approximately 5 milligrams of nitrogen and 0.08 milligram of phosphorus were necessary for each 100 milligrams of algae produced; a N : P ratio of 60 : 1.

Gerloff, G. C. and F. Skoog. 1957a.
Availability of Iron and Manganese in Southern Wisconsin Lakes for the Growth of *Microcystis aeruginosa*. Ecology, Vol. 38, No. 4, pp. 551–556.

Comparisons were made of the cell content of iron and manganese in cells of *Microcystis aeruginosa* collected from blooms in southern Wisconsin lakes with critical levels of the elements for maximum growth determined in the laboratory. These critical levels in the algal cells as determined in the laboratory were approximately 100 mg/l iron and 4 mg/l manganese. The cell contents of the elements in the lakes tested were in all cases so far in excess of these values that it seems unlikely the availability of either element is a factor in the development of blooms of this species in lakes.

Goering, J. J. and J. C. Neess. 1964.
Nitrogen Fixation in Two Wisconsin Lakes. Limnology and Oceanography, Vol. 9, No. 4, pp. 530–539.

Rates of biological nitrogen fixation in Lake Wingra and Lake Mendota, at Madison, Wisconsin, varied with light intensity. In Lake Mendota, rates were erratic and did not follow a regular seasonal pattern. Through the ice-free season, the rate of fixation was normally zero, but positive rates did occur without obvious relation to the concentrations of various forms of combined nitrogen. Significant fixation rates were found in Lake Wingra from mid-February to late October. The highest rate observed was 14.85 μg of nitrogen fixed per liter per 24 hours at a depth of 1 meter on July 26, 1961. Although the rates were significant throughout the ice-free season, they often fluctuated widely from date to date. Fixation occurred at times when nitrate and ammonia were present; however, maximum rates did not develop until nitrate and ammonia concentrations were low or undetectable. *Microcystis* and *Anabaena* were predominant genera present, and *Anabaena* probably was the significant nitrogen fixer.

Gotaas, H. B. 1954.
Discussion. Sewage and Industrial Wastes, Vol. 26, No. 3, pp. 325–326.

Dry weight algal yields of over 2,000 pounds per million gallons of primary sewage effluent have been obtained.

Grill, E. V. and F. A. Richards. 1964.
Nutrient Regeneration from Phytoplankton Decomposing in Sea Water. Journal of Marine Research, Vol. 22, No. 1, pp. 51–69.

A laboratory model of the regeneration of the inorganic nutrient salts of phosphorus, nitrogen, and silicon from diatom cells decaying in the dark while subject to bacterial attack was studied. The observations extended over a period of more than one year, but the significant changes appeared to have been restricted to the first five months.

The sudden increase in dissolved organic phosphorus, the decrease in particulate phosphorus, and the onset of silica re-solution after the eighth day suggest the autolytic release of dissolved organic phosphorus compounds from a dying diatom population. A rapid bacterial modification apparently followed and quickly consumed the dissolved organic phosphorus compounds, so that by the seventeenth day they had been completely reassimilated into particulate matter. At the end of the fourth week an abrupt decomposition of particulate phosphorus and an increase in inorganic phosphate began. By this time particulate nitrogen had begun to break down into ammonia and dissolved organic nitrogen compounds. Particulate phosphorus decreased until the fifth month but subsequently increased at the expense of the dissolved organic fraction. At the end of the experiment, 64 percent of the phosphorus was dissolved inorganic phosphate, 32 percent was particulate, and 4 percent was bound in dissolved organic compounds.

Particulate nitrogen began to break down into ammonia and dissolved organic compounds after the second week. Ammonia increased at a decreasing rate during the next 3 months and reached a maximum after 104 days. At the end of the experiment about 33 percent of the total nitrogen was ammonia, 39 percent was in particulate matter and 28 percent was in dissolved organic compounds; 40 percent of the particulate nitrogen present at the time of darkening had been converted to ammonia, 10 percent to dissolved organic compounds, and 50 percent remained in particulate form.

Guillard, R. R. L. and V. Cassie. 1963.
Minimum Cyanocolalamin Requirements of Some Marine Centric Diatoms. Limnology and Oceanography, Vol. 8, No. 2, pp. 161–165.

Marine planktonic algae often require thiamine, biotin, or vitamin B_{12} for growth. Based on the measurement of 10 cells randomly taken from 7 laboratory flasks each containing a different species of alga, the number of molecules of B_{12} required to produce one cubic micron of cell varied only from 5 to 18 in the different species irrespective of habitat or size, with an average of 10.1.

Harper, H. J. and H. R. Daniel. 1939.
Chemical Composition of Certain Aquatic Plants. Botanical Gazette, Vol. 96, p. 186.

Submerged aquatic weeds were found to be 12 percent dry matter and to contain an average of 1.8 percent total nitrogen (dry weight) and 0.18 percent total phosphorus.

Harris, E. and G. A. Riley. 1956.
Oceanography of Long Island Sound, 1952–1954. VIII. Chemical Composition of the Plankton. Bull. Bingham Oceanogr. Coll., Vol. 15, pp. 315–323.

The authors report that 6.6 percent of the wet weight of marine phytoplankton is organic matter and that 1 percent of the organic matter of diatoms is phosphorus.

Harvey, H. W. 1960.
The Chemistry and Fertility of Sea Waters. Cambridge University Press, American Branch, 32 East 57th St., New York 22, 240 pp.

Harvey states that although most of the phosphorus is absorbed by phytoplankton as orthophosphate ions, there is reason to believe that some may be absorbed as molecules of dissolved organic phosphate. From observations on a few species of phytoplankton, it appears likely: "(i) that they can absorb phosphate as quickly as they need it for rapid growth when its concentration in the water exceeds a threshold value whose magnitude lies in the region of 16 mg phosphate-P per m^3 [.016 mg/l]; (ii) that they can continue absorption of phosphate and its conversion into organic phosphorus compounds throughout both day and night; and (iii) that they can build up a reserve of storage product which cannot be used directly for further syntheses without prior dephosphorylation, and that light sets free or activates the phosphorylase concerned. . . . In nature nearly all the phytoplankton is eaten by animals, largely by zooplankton, and part is voided without being digested. Analyses of the faecal pellets of copepods indicate that most of the phosphorus does not remain in the voided particles of plants but dissolves in sea water. Part of this persists in the sea for a time as dissolved organic phosphorus compounds, and part is doubtless dephosphorylated by vegetable phosphorylases while in the animals' guts or while in faecal pellets. Some of the phytoplankton is digested and excreted by the animals as orthophosphate, excreted continuously whether the animals are well fed or starved. . . .

"All three inorganic nitrogen compounds, ammonium, nitrate and and nitrite, can be absorbed by phytoplankton, or at least by some species. There is a very marked preferential absorption of ammonium. . . . When the organisms become nitrogen-deficient, and are supplied with a nitrogen source, they absorb ammonium and nitrate in the dark converting them into organic compounds including chlorophyll. Nitrite cannot be utilized in the dark."

The proportion of nitrogen to phosphorus in phytoplankton is not a fixed ratio. The author cites Ketchum (1939a, b) to the effect that cells can be deficient in either and the ratio varies with the relative concentration in the medium. Direct experiment with a mixed culture indicated that some nine times more nitrogen than phosphorus was used. Experiments by Ketchum (1939b) with the diatom, *Phaeodactylum*, show a reduction in rate of cell division when phosphate present in the medium is less than some 17 mg phosphate-P per m^3. One experiment also showed that, with a sufficiency of phosphate, growth with as rapid in a sea water to which 47 mg nitrate-N per m^3 had been added, as in waters with greater additions. In other experiments the rate of nitrate absorption was reduced when the nitrate content of the medium was below 100–150 mg nitrate-N per m^3. "There is indirect evidence that the growth rate of phytoplankton in nature is reduced when the concentration of these nutrients falls below the threshold values suggested by the above experiments."

Ketchum, B. H. 1939a. The Absorption of Phosphate and Nitrate by Illuminated Cultures of *Nitzschia closterium*. American Journal of Botany, Vol. 26, p. 399.

Ketchum, B. H. 1939b. The Development and Restoration of Deficiencies in the Phosphorus and Nitrogen Composition of Unicellular Plants. Journ. Cell. Comp. Physiol., Vol. 18, p. 373.

Hasler, A. D. 1947.

Eutrophication of Lakes by Domestic Sewage. Ecology, Vol. 28, No. 4, pp. 383–395.

Eutrophication is defined as the intentional or unintentional enrichment of water. Hasler lists 37 lakes throughout the world varying in size from 9.4 to 1,500,000 hectares that show early eutrophy owing to domestic drainage. The Zürichsee, Switzerland, is composed of two distinct basins. The larger basin, 6,700 hectares, has become "strongly eutrophic" in the past 100 years owing to drainage from urban effluents. The smaller upper basin, 2,000 hectares, receives no major urban drainage and has retained its oligotrophic characteristics. In 1898, *Oscillatoria rubescens* erupted in the lower basin and has colored the outflowing stream copper-red on occasions since. Water transparency has become reduced as has the percent dissolved oxygen saturation in the deeper waters. *Oscillatoria rubescens* also occurred in the Hallwilersee, Switzerland, and in the Rotsee, Switzerland. In 1938 Mortimer measured the contribution of nitrogen to Lake Windermere, England, a lake of 1,482 hectares with a maximum depth of 67 meters. The total nitrogen income from drainage was 326 metric tons (195 pounds per acre), the outflow was 318 metric tons, and 8 metric tons were retained (2.4 percent) in the lake basin. "The abnormal acceleration of a process which is regarded as normal has had diverse effects, some of which are not for the best interests of man. The problem is especially serious because there is no way known at present for reversing the process of eutrophy."

Hasler, A. D. 1957.

Natural and Artificially (Air-Plowing) Induced Movement of Radioactive Phosphorus from the Muds of Lakes. International Conference on Radioisotopes in Scientific Research, UNESCO/NS/RIC/188 (Paris), Vol. 4, pp. 1–16.

In an undisturbed mud-water system, the percentage, as well as the amount of phosphorus which is released to the superimposed water is very small. In laboratory experiments, when P^{32} is placed at various depths in the mud the diffusion into the overlying non-circulating water is negligible if placed greater than 1 centimeter in the mud. Application of lime to the water, or to the mud, reduces the amount of soluble phosphorus available. Acidification of previously alkalized mud will, upon agitation, increase the amount of phosphorus entering solution. In an aquarium experiment, circulation of the water above phosphorus-rich mud with the aid of air bubbles increases the phosphorus in solution.

Hasler, A. D. and W. G. Einsele. 1948.
Fertilization for Increasing Productivity of Natural Inland Waters. Transactions of the Thirteenth North American Wildlife Conference, pp. 527–555.

On lakes with extensive littoral but small pelagic development, a fertilization rate of about 12 kilograms P per hectare (10.7 pounds per acre) is considered adequate if the growth of large aquatics is not too extensive and the water is at least medium hard. One application in the spring is sufficient. Large-scale fertilization is not generally advised because of the eutrophication inherent in such a plan. In lakes where a rapid change to eutrophy might be anticipated (i.e., where the hypolimnion in late summer may drop to 5 to 7 mg/l oxygen), the addition of normal aliquots of P (10.7 pounds per acre) leads, according to experience, to immediate eutrophication. The authors state that if the ratio of Fe to P is 2 : 1 or larger in the oxygen-depleted hypolimnion, the entire P will be bound to the oxidized Fe at turnover, thus $FePO_4$; this is insoluble and goes into the sediment.

Hayes, F. R. and N. R. Beckett, 1956.
The Flow of Minerals Through the Thermocline of a Lake. Archiv f. Hydrobiologie, Vol. 51, pp. 391–409 (from Putnam and Olson, 1960).

If water in a lake is to reach equilibrium following spring mixing and subsequent stratification, the salt concentration of the epilimnion must become less than the amount of salt at deeper levels because of the thermal gradient that is present. During summer stagnation, excess soluble materials from bottom sediments will migrate upward to the surface layers. If phosphorus or potassium is removed from the surface layer by plant activity, there will be a movement of salts from the bottom upward toward the surface.

Laboratory experiments were conducted in a refrigerated room (3–5° C.). A knife-type heater was set in the cover of a Pyrex battery jar and sampling tubes were arranged with horizontal openings at various depths in the jar so water could be removed without disturbing the stratification. Convection currents set up by the heater produced mixing of the epilimnion. The upper portion of the tank was insulated, the lower portion being in contact with the cold air of the room, with the result that a marked thermocline was quickly established. A large (400 liter) aquarium tank was set up in much the same way as the battery jar except for the series of sampling tubes. When salts were added, they were first mixed with a red dye so their movement could be traced. Chemical analysis of lake samples was made on a flame photometer.

For determination of temperatures of actual lake waters in the field, a portable conductivity bridge was used from a boat. The apparatus has a 75-foot cable to which was fastened the cable from a thermistor-type thermometer. By raising and lowering these cables, several hundred readings were taken in succession.

When sodium chloride was added to the epilimnion, there was a decline in concentration of the salt in the epilimnion at the end of 12 hours, accompanied by a corresponding increase in concentration in the hypolimnion; by 60 hours there was approximate equality of concentration of the salt throughout the tank. When salts were added to the hypolimnion, 27 days elapsed before there was an approximately equal distribution throughout the tank.

When conductivity experiments were utilized in four selected lakes, the data indicate that the equal distribution of base proceeded according to results observed in laboratory experiments, with a maximum at the bottom of the thermocline.

Production of minerals from bottom mud would result in diffusion of these minerals toward the surface and removal of nutrients by plants at the epilimnion will produce an upward flow of materials.

Hayes, F. R., J. A. McCarter, M. L. Cameron, and D. A. Livingstone. 1952.

On the Kinetics of Phosphorus Exchange in Lakes. Journal of Ecology, Vol. 40, pp. 202–216.

One thousand millicuries of radioactive phosphorus were added to the surface of an unstratified 10-acre lake having a depth of 22 feet over a 5-hour period. At the time of the experiment the lake contained 31 parts per billion of total phosphorus (3.7×10^3 grams in lake); the added 40 g of KH_2PO_4 contained 9.1 g of phosphorus, increasing the quantity in the lake by 0.25 percent. Mixing was practically complete on the first day, except in the deep hole where it took 3 days. After 8 days, the bottom water had more P^{32} than the rest of the lake. The loss of P^{32} for the lake as a whole was rapid at first reaching a pleateau after a month. The phosphorus turnover time was calculated at 5.4 and 39 days, respectively, for the water and solids. The gain by the bottom mud was greatest during the first 10 days leveling off in a month. It was calculated that a layer of mud about 2 centimeters thick participated in the phosphorus exchange.

Hoagland, D. R. 1944.
Lectures on the Inorganic Nutrition of Plants. Chronica Botanica Company, Waltham, Massachusetts, 226 pp.

Data from laboratory experiments provided evidence that with respect to the ions studied (K, Ca, Mg, H_2, PO_4, NO_3) their intake by young barley plants over a 12-hour interval was nearly the same during a dark period, with relatively small water absorption by the plants, as during a period of illumination, with relatively large absorption of water. It was not the movement of water that chiefly determined the amount of salt absorbed, but rather the metabolic activity of the plant.

Nitrate ions can be stored in plant cells, sometimes in large quantities, but normally their ultimate fate is to be reduced. In nutrient solution investigations the ammonium ion ordinarily can be completely substituted for the nitrate ion. Nitrate is utilized by plants only following its reduction, apparently through the stages of nitrite and ammonia. Light is not essential as a direct factor in its reduction. Excised barley roots and various other plant tissues can readily reduce nitrate in darkness.

Hoffman, D. A. and J. R. Olive. 1961.
The Use of Radio-phosphorus in Determining Food Chain Relationships in the Aquatic Environment. U.S. Atom. Energ. Comm., TID–13108, 46 pp; Water Pollution Abstracts, Vol. 35, No. 2, Abs. No. 270.

Experiments were carried out on the accumulation and concentration of phosphorus-32 by a simple food chain consisting of green algae, microcrustacea, *Daphnia*, and green sunfish. The concentration factors were found to be more than 25 at 10° C. The algae appeared to increase the amount of phosphorus for *Daphnia* during the first 24 hours and to decrease it after longer periods. The amount of phosphorus-32 accumulated by *Daphnia* was found to be proportional to the amount of surface area available for absorption of phosphorus.

Holden, A. V. 1961.
The Removal of Dissolved Phosphate from Lake Water by Bottom Deposits.
Verh. int. Ver. Limnol. 1959, Vol. 14, pp. 247–251; Water Pollution Abstracts, Vol. 35, No. 5, Abs. No. 889.

Experiments on the fertilization of Scottish locks and laboratory experiments on the loss of dissolved phosphate from water overlying mud deposits showed that aerobic bottom deposits can take up large amounts of phosphate although the rate of absorption is slow. When phosphate is added as a fertilizer, the rate of removal by the deposits may be slower than the uptake by macrophytic and attached flora. Most of the phosphate absorbed remains in the upper aerobic zone of the mud and most of it is converted to organic forms so that only a small proportion is available for release during periods of temporary anaerobic conditions in the mud. When the concentration of dissolved phosphate is high, there is some evidence of deeper penetration below the aerobic zone even in the absence of bottom fauna, although the burrowing organisms probably assist penetration. In unfertilized lakes, the quantity of phosphorus in the mud surface is very high compared with the equilibrium concentration in the overlying water. In shallow fertilized lakes, where the upper 15 cm of the bottom deposit may be involved in phosphate uptake, very large quantities can be removed from solution and much of that removed may be converted to forms which are unavailable for subsequent release to the water.

Hooper, F. F. and R. C. Ball. 1964.
Responses of a Marl Lake to Fertilization. Transactions of the American Fisheries Society, Vol. 93, No. 2, pp. 164–173.

A shallow marl lake was fertilized during three consecutive years with 10–10–10 or 12–12–12 at a rate of approximately 50 pounds per acre. Application was made in midsummer and evaluation of its effect was made by comparing data gathered in a pretreatment and a posttreatment period each year. Fertilization brought an immediate increase in suspended solids and a decrease in transparency. These changes appeared to be caused by a coalescence of suspended marl rather than by chemical precipitation or by an increase in phytoplankton. The maximum concentration of phosphorus recorded after fertilization was approximately the same value in all three years (45 to 47 parts per billion). This concentration represented approximately 52 percent of the phosphorus added in each of the years. In 1954 the maximum concentration of nitrogen after fertilization was 65 percent of the amount added to the water. In 1955 a maximum of only 37 percent of the added nitrogen appeared in samples. Fertilization did not substantially increase photoplankton but brought about a well marked increase in the production of periphyton algae in all three years.

Hooper, F. F. and A. M. Elliott. 1953.
Release of Inorganic Phosphorus from Extracts of Lake Mud by Protozoa. Trans. Amer. Microscopical Society, Vol. 72, No. 3, pp. 276–281.

Laboratory experiments suggest that certain benthic ciliates are capable of splitting inorganic phosphorus from the rather dilute solutions of organic phosphates that occur in lake and pond sediments. Authors cite Cooper (1941) who indicated that bacterial decomposition of plankton brings about rapid liberation of inorganic phosphorus in sea water; Renn (1937) who observed the release of phosphate from autolyzing bacterial cells in sea water; Stevenson (1949) who observed an increase in the phosphate content of sea water when agitated with bottom mud and attributed this to the breakdown of bacterial cells; Hutchinson (1941) who stated that regeneration of phosphate takes place to a large extent at the surface of the bottom mud in fresh-water lakes and involves the action of bacteria (Solimorskaja-Rodins, 1940); and Moore (1939) who reported an abundance of ciliates in this microcosm indicating that this group also contributes heavily to the decomposition processes taking place by metabolizing bacterial cells and particulate plankton detritus. The Hooper and Elliott experiments suggest that ciliates may also carry on a direct transformation of the dissolved organic phosphorus present in this habitat that is independent of bacterial activity.

Cooper, L. H. N. 1941. The Rate of Liberation of Phosphates in Sea Water by Breakdown of Plankton Organisms. Jour. Marine Biological Assoc. United Kingdom, Vol. 20, pp. 197–220.

Hutchinson, G. E. 1941. Limnological Studies in Connecticut. VI. Mechanism of Intermediary Metabolism in Stratified Lakes. Ecological Monographs, Vol. 11, pp. 21–60.

Moore, G. M. 1939. A Limnological Investigation of the Microscopic Benthic Fauna of Douglas Lake, Michigan. Ecological Monographs, Vol. 9, pp. 537–582.

Renn, C. E. 1937. Bacteria and Phosphorus Cycle in the Sea. Biological Bulletin, Vol. 72, pp. 190–195.

Solimorskaja-Rodins, A. C. 1940. The Mobilization of Phosphates in Water Reservoirs. Mikrobiologiia, Vol. 9, pp. 471–479.

Stevenson, W. 1949. Certain Effects of Agitation upon the Release of Phosphate from Mud. Jour. Marine Biological Assoc. United Kingdom, Vol. 28, pp. 371–380.

Hutchinson, G. E. 1957.
A Treatise on Limnology. John Wiley and Sons, New York, 1015 pp.

Phosphorus is cited as the element most important to the ecologist, since it is more likely to be deficient, and therefore to limit the biological productivity of any region of the earth's surface, than are the other major biological elements. The total phosphate in natural waters varies from less than 1 milligram per cubic meter (0.001 mg/l) to immense quantities in a very few closed saline lakes. The total quantity depends largely on geochemical considerations, usually being greater in waters derived from sedimentary rock in lowland regions than in waters draining the crystalline rocks of mountain ranges. Most relatively uncontaminated lake districts have surface waters containing 10 to 30 mg P per m^3, but in some waters that are not obviously grossly polluted, higher values appear to be normal. The soluble phosphate usually is of the order of 10 percent of the total. At the height of summer there may be a great increase in total phosphorus in the surface waters at times of algal blooms, though soluble phosphate is undetectable. One condition for the maximum development of such blooms may well be rapid decomposition and consequent liberation of phosphate in the littoral sediments during very warm weather. The phosphate would be taken up so fast by the growing algae that it never would be detectable. When massive amounts of soluble phosphate are added to a lake, it is rapidly taken up by the phytoplankton and then sedimented. The productivity of a lake is increased, but only for a time. The chemical relations of phosphorus in mud and water evidently constitute a self-regulating system.

The phosphorus cycle exhibited during extreme summer stratification is considered to involve the following processes:

1. Liberation of phosphorus into the epilimnion from the littoral, largely from the decay of littoral vegetation.
2. Uptake of phosphorus from water by littoral vegetation.
3. Uptake of the liberated phosphorus by phytoplankton.
4. Loss of phosphorus as a soluble compound, less assimilable than ionic phosphate, from the phytoplankton, probably followed by slow regeneration of ionic phosphate.
5. Sedimentation of phytoplankton and other phosphorus-containing seston, perhaps largely faecal pellets, into the hypolimnion.
6. Liberation of phosphorus from the sedimenting seston in the hypolimnion or when it arrives at the mud-water interface.
7. Diffusion of phosphorus from the sediments into the water at those depths at which the superficial layer of the mud lacks an oxidized micro-zone.

The mean ammonia-nitrogen content of rain falling in temperate regions, omitting large industrial towns is 0.64 mg per liter; the mean nitrate nitrogen content of the same samples is 0.196 mg per liter.

Ignatieff, V. and H. J. Page (Editors). 1958.
Efficient Use of Fertilizers. Food and Agriculture Organization of the United Nations, No. 43, 355 pp.

Between 1949 and 1958 the annual world consumption of fertilizers increased from 11.5 to 20.2 million tons.

The weights of plant nutrient elements in kilograms contained in good yields of common crop plants were given as follows:

Crop	Yield per hectare in metric tons	Kilograms		Percent	
		N	P	N	P
Cotton	1.1	73	28	6.6	2.5
Hay (mixed)	5.0	85	35	1.7	.7
Maize	3.8	106	39	2.7	1.0
Potatoes	20.2	140	39	6.9	.2
Soybeans	1.7	140	45	8.2	2.6
Tobacco	1.7	90	22	5.2	1.2
Wheat	2.0	56	22	2.8	1.1

On the average, fresh horse and cattle manures contain 20 to 25 percent dry matter, 0.30 to 0.60 percent nitrogen, 0.20 to 0.35 phosphoric acid (P_2O_5) and 0.15 to 0.70 percent potash (K_2O). Compared with commercial fertilizers on a unit-weight basis, animal manure is low in plant nutrients, especially in phosphorus. Thus, it is customarily applied at relatively much higher rates than fertilizers—probably 50 to 100 times higher.

Approximate composition of natural organic fertilizer materials was given as follows:

Material	Percent total nitrogen (N)	Percent total phosphorus pentoxide (P_2O_5)
Fish scrap or meal, dried	9.5	7.0
Guano, bat	8.5	5.0
Manure, cattle, dried	2.0	1.5
Manure, goat, dried	1.5	1.5
Manure, horse, dried	2.0	1.5
Manure, poultry, dried	5.0	3.0
Manure, sheep, dried	2.0	1.5
Seaweed, air-dry	1.5	.5
Sewage sludge, dried	2.0	2.0
Soybean meal	7.0	1.5
Tankage, process	9.0	.5
Wool waste	3.5	.5

In the United States, the usual dressings of N, and available P_2O_5 in kilograms per hectare were given as follows:

Crop	Kilograms per hectare	
	N	P_2O_5
Cotton	25 to 100	25 to 100.
Maize	100	60.
Sugarbeets	50 to 200	40 to 100.
Sugarcane	40 to 110	30 to 45.
Wheat	20 to 60	20 to 60.

Johannes, R. E. 1964a.

Phosphorus Excretion and Body Size in Marine Animals: Microzooplankton and Nutrient Regeneration. Science, Vol. 146, pp. 923–924.

Animal excretions are a major source of plant nutrients in the sea. In marine animals the rate of excretion of dissolved phosphorus per unit weight increases as body weight decreases. As a consequence microzooplankton may play a major role in planktonic nutrient regeneration. A 12-gram lamellibranch released an amount of phosphorus equal to its total phosphorus content every 438 days, the body-equivalent excretion time of a 0.6-mg amphipod was 31 hours, and that of an 0.4×10^{-3} μg ciliate was 14 minutes. An animal weighing 1 μg releases approximately 50 times as much phosphorus per unit weight as a 100-mg animal, while the smaller animal consumes only 5 to 8 times as much oxygen per unit weight.

Johannes, R. E. 1964b.

Uptake and Release of Dissolved Organic Phosphorus by Representatives of a Coastal Marine Ecosystem. Limnology and Oceanography, Vol. 9, No. 2, pp. 224–234.

A benthic diatom, a benthic amphipod, and mixed species of marine bacteria were used in studies of the uptake and release of dissolved organic phosphorus using the radionuclide P^{32}. Over one-third of the soluble phosphorus released by the amphipod was in organic form (0.79 μg-at. dissolved organic phosphorus per gram of animal per hour). Marine bacteria utilized 80 percent of this. Thirty percent was hydrolized in sterile media, possibly by alkaline phosphatase released by the amphipods. Bacteria-free diatoms released little dissolved organic phosphorus during growth, but released 20 percent of their total phosphorus as dissolved organic phosphorus after growth had ceased. Growing diatoms could reabsorb 40 percent of that released by senescent cells. Marine bacteria were able to absorb 92 percent. No regeneration of dissolved inorganic phosphate from dissolved organic phosphate in the presence of bacteria was observed. Marine bacteria, living or dead, released very little dissolved organic phosphate.

Johannes, R. E. 1964c.
Uptake and Release of Phosphorus by a Benthic Marine Amphipod. Limnology and Oceanography, Vol. 9, No. 2, pp. 235–242.

Lembos intermedius released phosphorus fractions into the water at the following rates: dissolved inorganic phosphate, 1.4 μg-at./g of animal (wet wgt.) per hr; dissolved organic phosphorus, 0.79 μg-at./g per hr; particulate phosphate, 7.9 μg-at./g per hr. Both metabolic waste phosphorus and phosphorus that had not been assimilated but had simply passed through the gut are present in all three fractions. The total phosphorus release rate drops by more than 50 percent in 2 hours when the animals are deprived of food. The physiological turnover time, the time it takes an amount of phosphorus equal to that in the tissues of the animal to pass through these tissues was 41 hours. The ecological turnover time, the time it takes an amount of phosphorus equal to that in the tissues to pass through the animal whether or not it is assimilated was 6.6 hours.

Juday, C. and E. A. Birge. 1931.
A Second Report on the Phosphorus Content of Wisconsin Lake Waters. Trans. Wis. Acad. of Sci., Arts and Letters, Vol. 26, pp. 353–382.

The mean quantity of soluble phosphorus in the surface waters of 479 lakes in northeastern Wisconsin was 0.003 mg/l; the range was from none in 9 lakes to a maximum of 0.015 mg/l in one. The mean quantity of organic phosphorus in the surface waters of these lakes was 0.020 mg/l; the range was from 0.005 mg to 0.103 mg/l.

The soil and subsoil of the lake district as well as the underlying strata through which the underground water passes are the chief sources of lascustrine phosphorus. Nineteen wells located on the shores of 13 widely distributed different lakes gave total phosphorus values of 0.002 mg/l to 0.197 mg/l with a mean of 0.029 mg/l.

Juday, C., E. A. Birge, G. I. Kemmerer, and R. J. Robinson. 1927.
Phosphorus Content of Lake Waters of Northeastern Wisconsin. Transactions of the Wisconsin Academy of Science, Arts, and Letters, Vol. 23, pp. 233–248.

The quantity of soluble phosphorus in surface waters of 88 lakes varied from none to 0.015 mg per liter. It was uniformly distributed from top to bottom during the spring circulation of the lakes but during summer stratification there was an increase in concentration of soluble phosphorus in the lower strata because of decomposition of organic material; two to ten times the amount was found in the lower levels than was present in surface waters.

Organic phosphorus varied from 0.007 mg per liter in the surface water of one lake to a maximum of 0.12 mg in a sample from the 15-meter level of another. In general, the amount of organic phosphorus was two to ten times greater than the amount of soluble phosphorus.

Juday, C., E. A. Birge and V. W. Meloche. 1941.
Chemical Analyses of the Bottom Deposits of Wisconsin Lakes. II. Second Report. Trans. Wis. Acad. Sci., Arts and Letters, Vol. 33, pp. 99–114.

Chemical analyses of the bottom deposits of 21 Wisconsin lakes expressed in percentage of the dry weight of the samples gave P_2O_5 values ranging from 0.05 to 0.61 percent; organic carbon, 6.62 to 40.5 percent; organic nitrogen, 0.55 to 2.94 percent; and organic carbon to organic nitrogen ratios from 7.5 to 14.4.

Kevern, N. R. and R. C. Ball. 1965.
Primary Productivity and Energy Relationships in Artificial Streams. Limnology and Oceanography, Vol. 10, No. 1, pp. 74–87.

The mean percentage and standard deviation of organic phosphorus in periphyton based on 113 samples collected on substrata in artificial streams was 0.21±0.11. The nitrogen content of the periphyton was estimated from the analysis of 62 samples, giving a mean percentage and standard deviation of 3.29±1.63. The ratio of the nitrogen content to the phosphorus content was calculated at 15.9 for the overall study.

The concentration of nutrients in mg/l added to the streams was as follows:

	July 1959	May 1960	July 1960	October 1960
KNO_3	114	[illegible]	2.7	2.7
K_2HPO_4	8	6	.3	.3

Knight, A. and R. C. Ball. 1962.
Some Estimates of Primary Production Rates in Michigan Ponds. Michigan Academy of Science, Arts, and Letters, Vol. 47, pp. 219–233.

Primary production rates were obtained from four ponds located on the Michigan State University experimental farm. The methyl orange alkalinity of these ponds varied between 46 and 96 ppm and the pH varied from 8.1 to 9.8. A comparison of primary productivity estimates for various ecosystems was presented as follows:

PRODUCTION RATE

Location	Method	Grams of organic matter per square meter per day		Macrophytes (dry weight)		Source
		Phyto-plankton	Peri-phyton	Grams per square meter per day	Pounds per acre	
Pond A		0.30	0.35	1.45	1,047	
Pond B		.46	.30	3.27	2,300	
Pond C		.44	.44	2.89	2,042	
Pond D		.64	.28	6.00	4,228	
Blind Lake, Mich.		1.20				Schelske, 1960.
Barents Sea	C^{14}	.56				Corlett, 1957.[1]
North Sea (annual range).	C^{14}	.20–3.00				Steel, 1957.[1]
South Atlantic	C^{14}	1.00–6.00				Steeman, 1954.
Red Cedar River, Mich.	Periphyton accrual.		.56			Grzenda, 1960.
Silver Springs, Fla.	Organic weight			7.40		H. T. Odum, 1957.
Sargasso Sea	Organic weight	.26				Riley, 1957.
Seaweed Beds, Nova Scotia.	Harvest			1.00		Tamiya, 1957.
Wheat (world average)	Harvest			2.30		Woytinsky & Woytinsky, 1953.
Green Lake, Wis.	Harvest				1,590	Rickett, 1924.
Lake Mendota, Wis.	Harvest				1,901	Rickett, 1922.

[1] Quoted by Strickland, 1960.

Corlett, J. 1957. Measurement of Primary Production in the Western Barents Sea. Paper presented at a Symposium of the International Council for the Exploration of the Sea. Bergen, 1957. Preprint C/no. 8.

Grzenda, A. R., and Morris L. Brehmer. 1960. A Quantitative Method for the Collection and Measurement of Stream Periphyton. Limnol. Oceanog., 5: 191–194.

Odum, H. T. 1957. Trophic Structure and Productivity of Silver Springs, Florida. Ecol. Mono., 27: 55–112.

Rickett, H. W. 1922. A Quantitative Study of the Larger Aquatic Plants of Lake Mendota. Trans. Wis. Acad. Sci., 20: 501–527.

Rickett, H. W. 1924. A Quantitative Study of the Larger Aquatic Plants of Green Lake, Wisconsin. Trans. Wis. Acad. Sci., 21: 381–414.

Riley, Gordon A. 1957. Phytoplankton of the North Central Sargasso Sea. Limnol. Oceanog., 2: 252–270.

Schelske, C. L. 1960. The Availability of Iron as a Factor Limiting Primary Productivity in a Marl Lake. Doctoral dissertation, Univ. Mich.

Steel, J. H. 1957. A Comparison of Plant Production Estimates Using C^{14} and Phosphate Data. J. Mar. Biol. Assoc. United Kingdom, 36 : 233.

Steeman, N. E. 1954. On Organic Production in the Oceans. J. Cons. Int. Explor. Mer., 19(3) : 309.

Strickland, J. D. H. 1960. Measuring the Production of Marine Phytoplankton. J. Fish. Res. Boards of Canada, Bull. No. 122, 172 pp.

Tamiya, Hiroshi. 1957. Mass Culture of Algae. Ann. Rev. Plant Physiol, 8 : 309–334.

Woytinsky, W. S., and E. S. Woytinsky. 1953. World Population and Production. The Twentieth Century Fund, New York.

Kratz, W. A. and J. Myers. 1955.
Nutrition and Growth of Several Blue-green Algae. American Journal of Botany, Vol. 42, No. 3, pp. 282–287.

Media and methods have been developed for the quantitative study of growth of three blue-green algae, *Anabaena variabilis*, *Anacystis nidulans*, and a strain of *Nostoc muscorum*. Temperature optima for the growth of all three species lie above 30° C. *Anacystis nidulans* at 41° C. has the highest growth rate yet reported for an alga, a generation time of about two hours. Both sodium and potassium are required for maintenance of maximum growth rate of all three species. Both ammonia and nitrate will serve as nitrogen sources for all three species. Urea is used by two species, free nitrogen only by one, *Nostoc muscorum*. All three species appear to be obligate phototrophs.

Krauss, R. W. 1958.
Physiology of the Fresh-water Algae. Annual Review of Plant Physiology, Vol. 9, pp. 207–244.

Phosphorus assimilation by P-deficient cells of *Chlorella* was measured by Al Kholy (1956) who found that growth continued until the P content dropped to 1 x 10^{-7} μg per cell. Mackereth (1953) determined that *Asterionella* can take up and store P from a concentration of less than 1 ppm. The limiting requirement is 0.06 μg P per 10^{6} cells, so 1μg P can produce 16 x 10^{6} cells before limitation sets in. Harvey (1953) has demonstrated that inositolhexaphosphate and glycerophosphate are absorbed by *Nitzschia closterium* in both light and darkness, but Rice (1953) showed that little conversion of inorganic P to organic compounds occurred in the dark.

Nitrogen fixation demonstrated among the algae only in the *Nostocaceae*, *Oscillatoriaceae*, *Scytonemataceae*, *Stigonemataceae*, and

Rivulariaceae (Fogg, 1951; Wielding, 1941) has been studied from economic as well as scientific points of view. Watanabe (1956) showed that, in four years after innoculation with *Tolypothrix tenuis*, fields of rice yielded 128 percent more than uninnoculated controls. The plants in the innoculated paddies contained 7.5 pounds more N per acre than the controls (Watanabe, 1951). De and Mandal (1956) also were able to obtain from 13 to 44 pounds of fixed nitrogen per acre from unfertilized, waterlogged rice-soils. Fogg (1951) found that *Mastigocladus laminosus* can fix 12.88 mg N per liter in 20 days. Atmospheric nitrogen, however, is not generally as efficient as a source for growth as NH^3 or nitrate. Kratz and Myers (1955) showed that N fixation in *Nostoc* supported only 75 percent of the growth obtained on nitrate.

Al Kholy, A. A., 1956. Physiol. Plantarum, Vol. 9, pp. 137–143.
De, P. K. and L. N. Mandal, 1956. Soil Sci., Vol. 81, pp. 453–459.
Fogg, G. E., 1951. J. Exptl. Botany, Vol. 2, pp. 117–120.
Harvey, H. W., 1953. J. Marine Biol. Assoc., U. K., Vol. 31, pp. 475–476.
Kratz, W. A. and J. Myers, 1955. Am. J. Botany, Vol. 42, pp. 282–287.
Mackereth, F. J., 1953. J. Exptl. Botany, Vol. 4, pp. 296–313.
Rice, T. R., 1953. Fishery Bull. of the Fish and Wildlife Service, Vol. 54, pp. 77–89.
Watanabe, A., 1951. Arch. Biochem. Biophys., Vol. 34, pp. 50–55.
Watanabe, A., 1956. Botan. Mag. (Tokyo), Vol. 69, pp. 820–821.
Wielding, S., 1941 Botan. Notiser, pp. 375–392.

Kuenzler, E. J. 1961.

Phosphorus Budget of a Mussel Population. Limnology and Oceanography, Vol. 6, No. 4, pp. 400–415.

The phosphorus budget of a *Modiolus demissus* Dillwyn population in a Georgia intertidal salt marsh was studied. Percentage phosphorus in mussel bodies decreased from 1 percent of the dry weight in small individuals to 0.6 percent in adults. The standing crop of phosphorus in the population was 37.2 mg P per m^2, the body fraction comprising 67 percent, the shell 30 percent, and the liquor 3 percent. Prorated losses and elimination rates ($\mu g\ P/m^2 day$) of the population were: mortality 21; gametes 11; dissolved organic 23; phosphate 260; and feces 460. Quantities of phosphorus present in natural marsh water (mg P/m^2) were: particulate 14; phosphate 19; and dissolved organic 6. The mussel population removed 5.4 mg P/m^2 of particulate phosphorus and 0.07 mg/P/m^2 of phosphate daily, of which 0.78 mg P/m^2 was required as food and 4.7 mg P/m^2 was deposited as pseudofeces. The turnover time of phosphorus in the population was 115 days.

Lackey, J. B. 1945.

Plankton Productivity of Certain Southeastern Wisconsin Lakes as Related to Fertilization. II. Productivity. Sewage Works Journal, Vol. 17, No. 4, pp. 795–802.

There is no definite criterion as to what actually constitutes a plankton bloom; however, when an organism reached or exceeded 500 per ml of raw water, it was termed a bloom. For very small organisms, as *Chlorella*, this might not be noticeable in the water, but for organisms such as *Ceratium hirundinella* or *Pandorina morum* vivid discolorations of the water are evident. Four of the 17 lakes studied had a collective total of 55 blooms during the 13-month study, whereas, 6 of the lakes did not have a single genus that showed 500 individuals per ml in the samples examined.

Lackey, J. B. 1949.

Plankton as Related to Nuisance Conditions in Surface Water. Limnological Aspects of Water Supply and Waste Disposal. American Association for the Advancement of Science, Washington, D.C., pp. 56–63.

A bloom is an unusually large number of plankters, usually one or a few species, per unit of the first few centimeters of surface water. An arbitrary definition has set 500 individuals per ml as constituting a bloom. In 16 southeastern Wisconsin lakes and three rivers in 1942–43, organism groups reached bloom proportions a total of 509 times.

Lackey, J. B. 1958.

Effects of Fertilization on Receiving Waters. Sewage and Industrial Wastes, Vol. 30, No. 11, pp. 1411–141[illegible]

Author lists ". . . benefits, at least from sewage, due to algal growths." These include (a) reoxygenation, (b) mineralization, and (c) production of a food chain. Three well recognized ills are: (a) algal toxicity, (b) aesthetic harm, and (c) buildup of biochemical oxygen demand. Green algae (*Micractinum*) growing in sewage in an experimental lagoon at the University of Florida had a BOD of 77.8 mg/l in five days. These algae. harvested from 500 ml of water, produced a dry weight of 0.0848 gram representing protoplasm, cellulose, and starch. Author cites Lackey et al., (1949) to the effect that after the oyster industry was well established in Great South Bay, the Long Island duck industry located around the Bay. The duck excreta at once began to fertilize the Bay. A heavy algal bloom resulted but the algae were not suitable food, or they produced external metabolites that adversely affected the oysters; thus, an annual four million dollar industry was destroyed. Letts and Adeney (1908) were cited as reporting on the pollution of estuaries and tidal waters by sewage and trade wastes in Ireland and Great Britain and relating the destruction of salmon and sea trout fisheries to the growth of vast beds of macroscopic green alga, *Ulva*, and its subsequent decay. That decay produced intolerable odors, blackened paint and silver in homes, and generally was damaging to real estate values.

Lackey, J. B., G. Vanderborgh, Jr. and J. B. Glancy. 1949. Plankton of Waters Overlying Shellfish Producing Grounds. Proc. National Shellfish Assn.

Letts, E. A. and W. E. Adeney. 1908. Pollution of Estuaries and Tidal Waters. Appendix VI, Fifth Report, Royal Commission on Sewage Disposal. H. M. S. Stationery Office, London.

Lackey, J. B. and C. N. Sawyer. 1945.
Plankton Productivity of Certain Southeastern Wisconsin Lakes as Related to Fertilization. I. Surveys. Sewage Works Journal, Vol. 17, No. 3, pp. 573–585.

A review of the investigative work on the Madison, Wisconsin, lakes problem is presented. Data are graphically plotted to show the relationship of biological activity and inorganic nitrogen concentrations in the water. As the biological activity is reduced during the cold winter months, the concentration of inorganic nitrogen in the surface water increases, and visa versa. The lakes below Madison, Wisconsin, were receiving 73 to 422 pounds per acre per year of inorganic nitrogen and 6.6 to 62.2 pounds per acre per year of inorganic phosphorus. They were being fertilized from 2.5 to 15 times as heavily as ordinary farm land. It was reported that, ". . . A normal application of nitrogen and phosphorus to farm lands seldom exceeds 30 and 12 lbs. per acre, respectively, and such applications are not usually made more than once every 3 or 4 years."

Lea, W. L., G. A. Rohlich, and W. J. Katz. 1954.
Removal of Phosphates from Treated Sewage. Sewage and Industrial Wastes, Vol. 26, No. 3, pp. 261–275.

Laboratory studies show it is possible to remove approximately 96 to 99 percent of the soluble phosphates from the effluent of a sewage treatment plant in a coagulation process employing aluminum sulfate.

ferrous sulfate, ferric sulfate, or copper sulfate. The residual phosphate concentration of the effluent following coagulation with 200 mg/1 of alum was 0.06 mg/1 expressed as P. The aluminum hydroxide floc resulting from the hydrolysis of alum may be recovered, purified by removing the adsorbed phosphates in the form of tricalcium phosphate, and re-used for further phosphorus removal in the form of sodium aluminate. This recovery and purification reduces by 80 percent the cost of chemicals required to remove phosphates from sewage treatment plant effluent. Pilot plant studies show that with the use of the alum recovery process, from 77 to 89 percent of the soluble phosphates can be removed. Filtering of the effluent showed that from 93 to 97 percent of the soluble phosphate can be removed. Concentrations of 0.578 to 0.80 mg/1 P would be expected to remain in the unfiltered effluent and 0.022 to 0.088 mg/1 P in the filtered effluent. As shown from pilot plant data, the cost of the chemicals per year, with chemical recovery, for a plant designed to treat 14.4 mgd would be $78,350 ($15 per 1 m.g.).

Love, R. M., J. A. Lovern, and N. R. Jones. 1959.
The Chemical Composition of Fish Tissues. Dept. of Scientific and Industrial Research Special Report No. 69, Her Majesty's Stationery Office, London, 62 pp.

Fishes in general contain 80 to 85 percent water. There is about 1 percent of ash in the muscle. The amount of phosphorus (P) in fish muscle from 49 specimens was reported to range from 68 to 550 mg % and average 190 milligrams percent [19 parts per million, wet weight].

Low, J. B. and F. C. Bellrose, Jr. 1944.
The Seed and Vegetative Yield of Waterfowl Food Plants in the Illinois River Valley. Jour. Wildlife Management, Vol. 8, No. 1, p. 7.

Coontail growths in the Illinois River valley approached 2,500 pounds per acre (dry weight), Sago pondweed 1,700 pounds per acre, and duckweed 244 pounds per acre. The authors found that the seed production of wild rice approached 32 bushels per acre; of pondweed, *Potamogeton americanus*, 20 bushels per acre; of Sago pondweed, 1.5 bushels per acre; and of coontail, 0.8 bushel per acre.

Ludwig, H. F., E. Kazmierczak, and R. C. Carter. 1964.
Waste Disposal and the Future at Lake Tahoe. Journal of the Sanitary Engineering Division, ASCE, Vol. 90, No. SA3, Proc. Paper 3947, pp. 27–51 (June).

The extraordinary clarity of 192-square-mile Lake Tahoe is threatened by the buildup of nitrogen and other nutrients reaching the lake from community wastes produced in the Tahoe Basin. Lake Tahoe has a maximum depth of 1,645 ft., and a volume of 122 million acre ft. Complete overturn of the water has not been observed but could possibly occur during unusually severe winters. Maximum transparency observed by Secchi disc was 136 feet, the minimum 49 feet. Primary productivity (rate of photosynthetic carbon fixation) of Lake Tahoe was 39 g C per sq. m. per yr. or an average of 99 mg C per sq. m. per day. Oligochaeta was found to be the dominant class of benthic organism ranging from a concentration of less than 1 per liter of sediment to 77 per liter of sediment. The nutrient balance for Lake Tahoe indicates that 706,200 pounds of chloride, 255,200 pounds of nitrogen, and 46,200 pounds of phosphorus enter the lake each year; and that 719,400 pounds of chloride, 28,600 pounds of nitrogen, and 3,300 pounds of phosphorus leave the lake. [Retention within the lake basin is 89 percent for nitrogen and 93 percent for phosphorus. The nitrogen loading to the lake is 2 lbs. per acre per yr.]

Mackenthun, K. M. 1962.
A Review of Algae, Lake Weeds, and Nutrients. Journal Water Pollution Control Federation, Vol. 34, No. 10, pp. 1077–1085.

Paper summarizes nutrient information from several sources. Data for several fertile Wisconsin streams are presented:

Stream	Flow c.f.s.	Nutrient loading (lb./yr./c.f.s.)		
		Inorganic N	Total P	Soluble P
Crawfish River at mouth:				
Normal	300	950	1,160	370
March	1,800	4,250	1,980	550
Rock River below Jefferson:				
Normal	1,400	470	900	290
March	6,600	4,160	3,280	590
Yahara River:				
Normal	30	457	140	86
March	47	5,350	512	100
Door Creek:				
Normal	15	7,740		115
March	60	13,350		215
Badfish Creek: Normal	31	4,616		150

Nutrient loadings and retentions (annual averages) for eutrophic algal producing Wisconsin lakes and oxidation ponds are presented:

Nutrient loading and retention (annual average)

Site	Date	Inorganic nitrogen		Soluble phosphorus	
		Loading (lb./yr./acre)	Retention (Percent)	Loading (lb./yr./acre)	Retention (Percent)
(a) LAKES					
Mendota		20		0.6	
Monona	1942-43	73	48	7	64
	1943-44	90	70	9	88
Waubesa	1942-43	422	50	62	−26
	1943-44	448	64	64	25
Kegonsa	1942-43	168	44	34	−21
	1943-44	156	61	38	12
Koshkonong	1959-60	90	80	40	30-70
(b) OXIDATION PONDS					
Jct. City	1957	2,427	97	402	94
	1959	3,760	85	3,680	80
New Auburn	April	4,000	6	707	0
	August	4,600	98	1,350	58
Spooner	December	3,614	65	1,168	0
	August	3,430	93	1,680	66

Mackenthun, Kenneth M. Unpublished Data.

Pentavalent arsenic will appear as phosphorus in the standard phosphorus determination. False soluble phosphorus determinations produced by known concentrations of pentavalent arsenic in distilled water as demonstrated in the Wisconsin State Laboratory of Hygiene were as follows:

As (mg./l.)	Apparent P (mg./l.)	As (mg./l.)	Apparent P (mg./l.)	As (mg./l.)	Apparent P (mg./l.)
0	0	0.163	.08	0.7	.34
0.016	.01	0.2	.11	1.0	.43
0.033	.02	0.326	.16	1.3	.54
0.05	.03	0.4	.20	2.0	.78
0.065	.03	0.5	.24	3.0	1.08
0.1	.06	0.65	.33		

Aquaria tests indicate that a 5-mg/l concentration of trivalent arsenic will produce the same pseudo phosphorus reading as a 5-mg/l pentavalent arsenic concentration in 15 days in full sunlight at room temperature. This transition may take 40 days in the dark under cooler temperatures. In a vessel filled with lake water to which only sodium arsenite was added, the arsenic content remained relatively constant throughout the forty-day period. On the other hand, when lake water was superimposed upon 3 inches of lake bottom mud, arsenic and pseudo phosphorus concentrations diminished rapidly, especially after

10 days. A small amount of arsenic remained in solution in the aquaria at the end of 40 days, but much had been absorbed by the layer of mud on the bottom.

Lakes that have received sodium arsenite for the control of aquatic vegetation may contain sufficient arsenic in solution to interfere with phosphorus determinations.

Mackenthun, K. M., W. M. Ingram, and R. Porges. 1964. Limnological Aspects of Recreational Lakes. U.S. Public Health Service Publication No. 1167, 176 pp.

Moyle (1961) quotes a number of investigators converting their data on bottom fauna standing crop to pounds per acre (wet weight). Some typical values include 248 pounds per acre from a Minnesota pond (Dineen, 1953); 67 to 82 pounds per acre in an unfertilized Michigan pond, and 101 to 127 pounds per acre in a fertilized Michigan pond (Ball, 1949); 124 pounds per acre in Lizard Lake, Iowa (Tebo, 1955); 398 pounds per acre in the Mississippi River system with no weeds, and 1,143 pounds per acre in the Mississippi River system in weeds (Moyle, 1940); and as much as 3,553 pounds per acre in a *Chara* bed in a slow stream in New York (Needham, 1938). Borutsky (1939) working on the deepwater benthos of a lake in Russia, concluded that throughout the year 6 percent of the biological productivity was lost as emerged insects that perished outside the lake basin, 14 percent was eaten by fish, 55 percent was returned to the lake as dead larvae, cast skins, etc., and 25 percent remained to assure the continuation of the species the following year.

Basic sources of nutrients to lakes and reservoirs are (a) tributary streams carrying land runoff and waste discharges (b) the interchange of bottom sediments, and (c) precipitation from the atmosphere. Studies of Wisconsin waste stabilization ponds indicate annual per capita contributions of 4.1 pounds of inorganic nitrogen and 1.1 pounds of soluble phosphorus (Meckenthum and McNabb, 1961). The Nine-Springs Sewage Treatment Plant provides primary and secondary treatment for all wastes from Madison, Wis., metropolitan area of 85 square miles with a population of about 135,000. The effluent from the secondary processes—one-fourth settled sewage from trickling filters and three-fourths from activated sludge—has an annual per capita contribution of 8.5 pounds of inorganic nitrogen and 3.5 pounds of soluble phosphorus.

Land runoff may often be the major contributor of nutrients to the tributary stream. The annual loss of nitrogen and phosphorus per acre from a planting of corn on a 20 percent slope of Miami silt loam was found to be 38 and 1.8 pounds, respectively; on an 8 percent slope, this was reduced to 18 pounds of nitrogen and 0.5 pound of phosphorus (Eck et al. 1957). In a study of the lower Madison lakes, Sawyer et al. (1945) found that the annual contribution of inorganic nitrogen per acre of drainage area tributary to Lake Monona was 4.4 pounds, Lake Waubesa, 4.9 pounds, and Lake Kegonsa, 6.4 pounds.

Sawyer et al., (1945) found the nitrogen and phosphorus content of the bottom muds in the Madison lakes to be 7,000 to 9,000 μg/g dry weight and 1,000 to 1,200 μg/g dry weight, respectively.

As fixed nitrogen enters the reservoir, it is incorporated in the biomass as an element of protein. Upon death or excretion, nitrogen is liberated for reuse. During this process some is lost: (a) in the lake effluents (as much as 40 percent), (b) by diffusion of volatile nitrogen compounds from surface water, (c) by denitrification in the lake, and (d) in the formation of permanent sediments.

Likewise, phosphorus, taken up in the web of life, is liberated for reuse upon death of the organism (Cooper, 1941). Some may settle into the hypolimnion with the sedimentation of seston (all living and nonliving floating or swimming plants or animals) or in fecal pellets, and some may be released at the mud-water interface (Hooper and Elliott, 1953).

The Madison Lakes problem at Madison, Wisconsin, has been a subject of nationwide discussion, intensive investigation, and legislative and legal action for many years. The series of Yahara River lakes at Madison, Wisconsin, includes Lake Mendota, Lake Monona, Lake Waubesa, and Lake Kegonsa, respectively. Madison, Wisconsin, is located between Lake Mendota and Lake Monona. In the early history of the city, Lake Monona received raw sewage and later treated sewage effluent from the City of Madison. In 1926, the Nine-Springs Sewage Treatment Plant was placed in operation and the effluent from this installation was carried via Nine-Springs Creek to the Yahara River above Lakes Waubesa and Kegonsa. The enrichment of these lower Madison Lakes by the highly nutritious effluent produced nuisance algal growths, offensive odors, and periodic fish kills. These conditions led to innumerable complaints, much debate, and eventually, in December 1958, legislative and legal action forced the diversion of the effluent from the Madison Metropolitan Sewerage District's Nine-Springs Treatment Plant around the lower Madison Lakes.

The 1942–43 report to the Governor's Committee on a study of the Madison Lakes (Sawyer et al., 1945) contained results of over 15,000 chemical determinations mostly on nitrogen and phosphorus, along with appropriate flow data. Algal counts were also made and correlated with nutrients found. Major conclusions reached were that (1) the biological productivity of the local lakes is a function of the loading of inorganic nitrogen on each lake, (2) the soluble phosphorus content of the water may be a factor in limiting the rate of biological activity and in determining the nature of the growths when its concentration drops below 0.01 mg/l, (3) drainage from improved marsh land is approximately two to three times as rich in inorganic nitrogen as drainage from ordinary farm land, and (4) high biological productivity and nuisance conditions do not always occur simultaneously.

The 1943–1944 report, which gives the results of over 21,000 chemical determinations and complementary biological studies, ". . . strengthen the conviction that inorganic forms of nitrogen and phosphorus are the main factors in providing fertilizing elements for algal blooms."

The nutrients' stimulation of algal production can lead to the formation of a mass of organic matter greater than that of the original waste source (Renn, 1954). In an enriched environment, algae respond so well to incoming nutrients that the oxygen required for the respiration of the resultant algal mass alone surpasses the biochemical oxygen demand (BOD) of the incoming food material. Lake Winnebago, Wisconsin (area 213 square miles), produces heavy algal populations. In July, when the lower Fox River carried a heavy algal load from Lake Winnebago, the ultimate BOD in the river above the sources of industrial and municipal wastes ranged to 660,000 pounds of oxygen demand each day (Scott et al., 1956).

Ball, R. C., 1949. Experimental Use of Fertilizer in the Production of Fish-Food Organisms and Fish. Michigan State College Agricultural Experiment Station, East Lansing, Tec. Bull. 210. 28 pp.

Bush, A. F. and S. F. Mulford, 1954. Studies of Waste Water Reclamation and Utilization. California State Water Pollution Control Board, Sacramento, Publication No. 9, 82 pp.

Cooper, L. H. N., 1941. The Rate of Liberation of Phosphates in Sea Water by Break-down of Plankton Organisms. Jour. Marine Biological Association, United Kingdom, *20* : 197–220.

Dineen, C. F., 1953. An Ecological Study of a Minnesota Pond. Am. Midl. Nat., *50* (2) : 349–356.

Eck, P., M. L. Jackson, O. E. Hayes and C. E. Bay, 1957. Runoff Analysis as a Measure of Erosion Losses and Potential Discharge of Minerals and Organic Matter into Lakes and Streams. Summary Report, Lakes Investigations, University of Wisconsin, Madison, 13 pp. (mimeo).

Hooper, F. F. and A. M. Elliott, 1953. Release of Inorganic Phosphorus from Extracts of Lake Mud by Protozoa. Trans. Am. Micr. Soc., *72* (3) : 276–281.

Mackenthun, K. M., L. A. Lueschow and C. D. McNabb, 1960. A Study of the Effects of Diverting the Effluent from Sewage Treatment upon the Receiving Stream. Wis. Acad. Sci., Arts and Letters, *49* : 51–72.

Mackenthun, K. M. and C. D. McNabb, 1961. Stabilization Pond Studies in Wisconsin. Jour. Water Pollution Control Federation, *33* (12) : 1234–1251

Metzler, D. F., et al., 1958. Emergency Use of Reclaimed Water for Potable Supply at Chanute, Kans., Jour. Am. Water Works Association, *50* (8) : 1021–1060.

Moyle, J. B., 1940. A Biological Survey of the Upper Mississippi River System (in Minnesota). Minn. Dept. Cons. Fish. Inv. Rept. No. 10, 69 pp.

Moyle, J. B., 1961. Aquatic Invertebrates as Related to Larger Water Plants and Waterfowl. Minn. Dept. Cons. Inv. Rept. No. 233, pp. 1–24 (mimeo.).

Needham, P. R., 1938. Trout Streams. Comstock Publishing Co., Ithaca, N.Y., 233 pp.

Sawyer, C. N., J. B. Lackey and R. T. Lenz, 1945. An Investigation of the Odor Nuisances Occurring in the Madison Lakes, Particularly Monona, Waubesa and Kegonsa from July 1942–July 1944. Report of Governor's Committee, Madison, Wisconsin, 2 Vols. (mimeo.).

Scott, R. H., B. F. Lueck, T. F. Wisniewski and A. J. Wiley, 1956. Evaluation of Stream Loading and Purification Capacity. Committee on Water Pollution, Madison, Wis., Bull. No. 101 (mimeo.).

Tebo, L. B., 1955. Bottom Fauna of a Shallow Eutrophic Lake, Lizard Lake, Pocahontas County, Iowa. Am. Midl. Nat., *54*(1) : 89–103.

Mackenthun, K. M., L. A. Lueschow, and C. D. McNabb. 1960. A Study of the Effects of Diverting the Effluent from Sewage Treatment upon the Receiving Stream. Trans. Wisconsin Acad. Sci., Arts, Letters, Vol. 49, pp. 51–72.

Samples from a 26 bi-weekly period from the receiving streams were analyzed both before and after diversion of 20 million gallons per day of primary and secondary treated sewage from Madison, Wisconsin, from a population of about 135,000. The first receiving stream, Badfish Creek, is approximately 16½ miles long and has an average slope of about six feet per mile. Biological and chemical data for a point about mid-way down Badfish Creek before (1956) and after (1959) diversion were summarized as follows:

	Pounds per day			
	Range		Mean	
	1956	1959	1956	1959
Phytoplankton	56–791	247–1,435	250	622
Organic N	13–71	206–447	30	286
Inorganic N	89–143	2,171–4,246	110	3,153
Soluble P	7–12	996–1,701	9	1,351
Biochemical oxygen demand	39–113	755–2,333	75	1,602
Dissolved oxygen	386–636	413–1,749	475	904
Flow (c.f.s.)	8–10	40–48	9	43

Following diversion, long streamers of filamentous green algae (*Stigeoclonium* and *Rhizoclonium*), some of which were estimated to be 50 feet in length, were attached to bottom materials at numerous locations in Badfish Creek. *Oscillatoria* covered the bottom in the upper area. Severe stream degradation following diversion was indicated by the community of stream biota.

MacPherson, L. B., N. R. Sinclair, and F. R. Hayes. 1958.
Lake Water and Sediment. III. The Effect of pH on the Partition of Inorganic Phosphate Between Water and Oxidized Mud or its Ash. Limnology and Oceanography, Vol. 3, pp. 318–326; Water Pollution Abstracts, Vol. 32, No. 4, Abs. No. 622.

Dried and reconstituted mud from primitive, medium, productive, and acid bog lakes was shaken with water to achieve phosphorus equilibrium. Minimal phosphorus was released from the mud at pH 5.5 to 6.5, and the concentration varied from scarcely detectable up to 0.2 mg/l in productive lakes. Greater acidity caused a slight increase of phosphorus in the water, up to 0.3 mg/l, and alkalinity a larger increase, up to 0.5 mg/l. At all pH values the amount of phosphorus released increased in the order of lake type from primitive to acid bog. When 1 mg/l phosphorus was added to the water before shaking, it was not taken up by muds from acid bog and productive lakes, while unproductive lake muds removed most of the added phosphorus under acid conditions, but not at pH values of 7.0 or more.

Malhotra, S. K., G. F. Lee, and G. A. Rohlich. 1964.
Nutrient Removal from Secondary Effluent by Alum Flocculation and Lime Precipitation. International Journal of Air and Water Pollution, Vol. 8, Nos. 8 and 9, pp. 487–500.

The removal of phosphorus and nitrogen compounds from biochemically treated wastewater effluents by alum flocculation and lime precipitation was investigated. Samples of secondary effluent were flocculated or precipitated in accord with conventional jar test procedures. The phosphorus removal was found to be highly pH-dependent with an optimum pH of 5.57±0.25. At this pH an alum dose of 250 mg/l removed 95% of total phosphorus, 55% of the chemical oxygen demand, 60% of the organic nitrogen, 25% of the NO_3-N and NO_2-N, 17% of the apparent ABS, and none of the ammonia-N.

A dose of 600 mg/l $Ca(OH)_2$ raised the pH of the sample to 11.0 and removed 99% of the total phosphorus.

The estimated chemical costs for removal of 95% of the phosphorus by lime and alum were $32 and $73 per million gallons, respectively.

Matheson, D. H. 1951.
Inorganic Nitrogen in Precipitation and Atmospheric Sediments. Canadian Journal of Technology, Vol. 29, pp. 406–412.

In an investigation covering 18 months, daily determinations were made of the inorganic nitrogen contained in precipitation and atmospheric sediments collected at Hamilton, Ontario. The nitrogen fall for the whole period averaged 5.8 lb. N per acre per year. Sixty-one percent of the total nitrogen was collected on 25 percent of the days when precipitation occurred. The balance, occurring on days without precipitation, is attributable solely to the sedimentation of dust. Ammonia nitrogen averaged 56 percent of the total.

McGauhey, P. H., R. Eliassen, G. Rohlich, H. F. Ludwig, and E. A. Pearson. 1963.

Comprehensive Study on Protection of Water Resources of Lake Tahoe Basin Through Controlled Waste Disposal. Prepared for the Board of Directors, Lake Tahoe Area Council, Al Tahoe, California, 157 pp.

The amount of nitrogen from pollen may be as high as 2 to 5 kg nitrogen per hectare per year in a forested area. The pollen contains chloride and phosphate in addition to nitrogen, but as a significant amount of pollen was seen to be intact in the sediments it cannot be assumed that these materials are released to the lake water.

The nitrogen and phosphorus content in trout is about 3 percent N and 0.2 percent P by weight, giving a maximum amount of 300 kg N and 20 kg P taken out of Tahoe Lake annually as fish.

Results of 14 samples of the upper 10 cm of Lake Tahoe sediments indicate a moisture content ranging from 17.5 to 84.5 percent, Kjeldahl nitrogen from 0.06 to 16.6 mg/g dry weight, total carbon 0.06 to 198.0 mg/g dry weight, and carbon nitrogen ratios from 3.7 to 28.4.

It was assumed that the average per capita refuse produced in the watershed (originating from food and other materials imported into the watershed) is 2 pounds per day of which 1.0 percent is nitrogen (as N) and 0.5 percent is phosphorus (as P).

Unit design factors suggested for domestic wastes were as follows:

Average sewage flow, gallons per capita per day:	
Residential and commercial areas	90
Recreational areas	30
BOD, mg/l	250
Phosphate, mg/l P	8
Total Nitrogen, mg/l N	45

Passage of water to the ground by infiltration from ponds has little or no effect on nutrient concentrations, and subsequent flow through the ground effects only partial removal of nutrients. Nitrate appears to be transported by ground waters without significant reduction by earth materials. Percolation of water through the ground does not materially reduce the concentrations of various chemical constituents introduced.

Consideration was given to tertiary waste treatment methods. The known methods which might be feasible may be classified as follows:

1. Preblooming using algae ponds.
2. Physical-chemical methods: These include nitrogen removal by air stripping of ammonia and/or by ion exchange; phosphate removal by precipitation with lime, alum, ferric iron, or other precipitating agents; and complete distillation.
3. Controlled biological methods.

Tertiary Treatment by Preblooming

"Nutrient removal by preblooming in ponds involves conversion of waste nutrient materials present to algal cell material through photosynthesis followed by the removal of the algal cells from the pond effluent. Removal of cells from the waste effluent may be accomplished by centrifuging, filtering, or coagulation. Coagulation may have an added advantage in obtaining a higher degree of removal of residual phosphates.

"Nutrient removal in such processes is a function of the size of the algae crop. Factors affecting production of algae are nutrient concentrations, sunlight, and other environmental characteristics such as depth and temperature. Climate may place severe restrictions on the size of the algae crop and hence reduce nutrient removal efficiency. Investigations by Fitzgerald show clearly that in favorable summer conditions high decreases in inorganic nitrogen occurred (13–6). For the most of the year however, nitrogen removal was less than 50 percent and even negative values were recorded in the winter-time. There were only 33 days in 1956 and 76 days in 1957 when nitrogen removals were greater than 50 percent. The nitrogen removals averaged about 30 percent for the year. Phosphate reductions were high during periods of high algae productivity, coinciding with high pH values, indicating phosphate precipitation. This was borne out by the fact that winter effluent phosphate concentrations frequently surpassed influent levels, a phenomenon probably due to the dissolution of the phosphate previously precipitated. The data presented by Fitzgerald were confirmed by the observations of Parker (13–7) whose study involved a series of eight ponds used in series. The decrease in nitrogen content was only about 51 percent during the summer (average temperature 70° F) and 12 percent during the winter (average temperature 48° F). Experimental studies conducted by Oswald et al (13–8) on the use of "high-rate" ponds for the commercial production of algae showed about 70 percent nitrogen removal and 50 percent phosphate removal due to algal action alone, and near-complete removal of phosphate was possible through harvesting by means of coagulation with alum. These results, however, were obtained under very favorable climatic conditions.

"Considering the climatic conditions within the Tahoe Basin, it is obvious that the degree of nutrient removal which could be anticipated during the winter months would be negligible, and reasonably successful operation could only take place during the summer months (June through August). As in land disposal by cropping, therefore, winter storage facilities would be needed, and the entire yearly flow would have to be treated in a three-month period. Using the most efficient type of high-rate ponds, the area requirement is approximately 10 acres per mgd of waste effluent. The ponds would be about 8 to 12 inches deep completely lined and equipped with low head pumps for recirculation. The estimated cost of such ponds is $20,000 per acre including land. Based on the ultimate average flow estimated for El Dorado County (11 mgd) and assuming an operational period of three months (not including the two week start-up period normally required), approximately 440 acres of ponds would be required. The cost of the ponds alone (including land) would be about $8,800,000. In addition to the ponds and storage facilities, the complete system would require pretreatment facilities, and algae removal system consisting of coagulation and sedimentation basins, and a system for dewatering and drying the algae cells.

Physical-Chemical Methods

"Physical-chemical tertiary treatment methods meriting consideration include nitrogen removal by ion exchange, air stripping of ammonia, phosphate removal by using the Foyn Cell or by coagulation, and complete demineralization through distillation.

"*Nitrogen Removal Using Ion Exchangers:* Studies carried out by Nesselson (13–9) at the University of Wisconsin indicate that strongly basic anion exchangers perform satisfactorily for the removal of nitrate nitrogen, and that removal of ammonia may be accomplished using a cation exchange resin. The ion exchange process may be used to remove these nutrients from the effluents of conventional secondary treatment plants (activated sludge or trickling filters). Inasmuch as almost 60 percent of the nitrogen in raw sewage is in the form of ammonia, and because this percentage can be increased through controlled operation of conventional biological processes (through conversion of organic nitrogen to ammonia), use of a cation exchanger in series with the conventional plant may remove a major fraction of the nitrogen.

"Nesselson indicates that Nalcite HCR has an exchange capacity of 16 to 22 kilograms per cu ft (as $CaCO_3$) when used for the removal of ammonia nitrogen from activated sludge effluents. The exchanger operates with an efficiency of 1.4 to 2.5 lbs of salt (NaCl) per kilogram of cations removed. Amberlite IR–120 has corresponding values of 13 to 17 kg per cu ft and 1.3 to 2.6 lbs NaCl per kg of cations removed.

A minimum volume of 6 percent of the influent feed was required for regeneration. This quantity of water (60,000 gallons per mg of water treated) must be disposed of somehow, preferably by evaporation. This problem, plus the fact that the process has never been developed beyond the laboratory stage, and moreover would be more costly than competitive biological processes not employing resins, rules out the use of ion exchangers at Tahoe.

"*Nitrogen Removal by Air Stripping of Ammonia:* Because ammonia nitrogen represents the greater portion of nitrogen present in sewage and sewage effluents, air stripping of this component as a nitrogen removal method has been considered. Kuhn (13–10), in laboratory studies at the University of Wisconsin on air stripping in packed towers, found that about 92 percent removal of ammonia nitrogen could be obtained in a percolation tower seven feet high with air to liquid loadings of about 520 to 550 cu ft per gallon of flow. In an activated sludge plant, normal air requirements vary from about 0.2 to 2.5 cu ft per gallon of sewage treated. These figures show that although the process is technically sound it is economically prohibitive.

"*Phosphate Removal Using the Foyn Cell:* Dr. Ernst Foyn at Oslo, Norway, has developed a process referred to as 'electrolytic' sewage purification (13–11). A divided container is equipped with electrodes connected to the negative and positive poles of a battery. One portion of the chamber contains sea water, the other a mixture of sewage with 10 to 15 percent sea water. Chlorine is developed at the graphite anode and hydrogen and alkali in the chamber containing the iron cathode, thus creating chemical conditions necessary for the precipitation of phosphate. The phosphate is adsorbed on the magnesium hydroxide floc or precipitated and floated to the surface by the hydrogen bubbles. Pilot plant investigations showed that a detention period of about 1.5 hrs resulted in phosphate removal of 60 to 80 percent and a reduction in Kjeldahl nitrogen of about 60 percent. It is apparent that because of the sea water requirement (115 percent of the volume of sewage treated) the Foyn Cell is scarcely feasible for use at Tahoe.

"*Removal of Phosphate by Precipitation:* A series of laboratory and pilot plant studies were conducted by the University of Wisconsin, both in the laboratory and at the Nine Springs Treatment Plant in Madison, Wisconsin, on phosphate removal by precipitation using ferrous sulfate, ferric sulfate, cupric sulfate, diatomaceous earth, and aluminum sulfate as coagulation agents (13–11). As a result of these studies the following conclusions were made:

(1) Under laboratory conditions it is possible to remove 96 to 99 percent of the soluble phosphates from sewage treatment plant effluents. This removal can be accomplished in a precipitation or coagulation process employing any of a number of coagulants (alum, ferrous sulfate, ferric sulfate, or copper sulfate).

(2) Alum appears to be the most suitable coagulant for the following reasons: (a) The residual phosphate concentration of the effluent following coagulation with 200 ppm of alum is, on the average, 0.06 ppm (expressed as P); (b) the optimum pH range for the removal of phosphates through coagulation with alum is 7.1 to 7.7; and (c) the aluminum hydroxide floc resulting from the hydrolysis of alum may be recovered, purified by removing the absorbed phosphates in the form of tricalcium phosphate, and re-used for further phosphorus removal in the form of sodium aluminate. This recovery and purification reduces the overall cost of chemicals by 80 percent.

(3) Pilot plant studies show that with the alum recovery process, from 77 to 89 percent of the soluble phosphates can be removed. By filtering the effluent up to 93 to 97 percent can be removed. Improved settling facilities should give intermediate levels of removal.

"In experiments conducted by Wuhrmann (13–12) at Zurich it was shown that lime was the most economical precipitating agent, especially with the extra addition of a small amount of ferric iron as a coagulant aid. Also, the lime precipitate showed superior settling rates and produced a slurry much easier to dewater than sludge from alum or iron coagulation. Although the alkalinity of the water used in the Zurich experiments (200 mg/l) was much higher than at Tahoe, it appears that lime precipitation might prove to be advantageous to alum or iron for use at Tahoe. Owen (13–13) has also reported on the use of lime for removing phosphorus from sewage.

"*Pitcon Process:* A tertiary process which includes this type of phosphate removal, known as the "Pitcon" process, has recently undergone a series of pilot scale tests at the South Tahoe Public Utility District (13–14). The pilot scale tests were carried out by Cornell, Howland, Hayes, and Merryfield in cooperation with Clair A. Hill and Associates, for the purpose of developing design criteria and cost data. The tertiary plant tested at STPUD included two basic processes, the first being phosphate removal by alum coagulation (with the aid of polyelectrolytes) followed by filtration through a series of activated carbon columns to remove ABS (alkyl benzene sulfonates).

"In November 1962 a special test run of the pilot facility was arranged by Cornell, Howland, Hayes, and Merryfield, during which members of the Board of Consultants and of the staff of Engineering-Science, Inc., were present as observers. At this time composited samples (comprising several grab samples) were taken of the process influent (activated sludge effluent) and process effluent. These were analyzed by Engineering-Science, Inc., with results as shown in Table 13–II. These data indicate the process accomplished a removal of about 96 percent of both total and soluble phosphates, within the expected range. With respect to total nitrogen, the process effected little if any removal, the principal effect being conversion of organic nitrogen to ammonia. The total nitrogen was 28.9 mg/1 (as N) in the influent and 28.8 mg/l in the effluent.

"*Distillation:* Distillation, although very expensive, does presently possess one major advantage over all other tertiary treatment methods, namely its ability to completely demineralize the waste thus producing an effluent practically devoid of all nutrients such as nitrogen, phosphorous, vitamins, micronutrients, iron, etc., all or any of which might influence algae production.

"Although considerable cost data are available for the distillation of sea water, there has been little experience in the distillation of wastes on which reliable cost estimates may be based. Preliminary estimates have been made by the Advanced Waste Treatment Program of the U.S. Public Health Service (13–15), based on comparisons with sea water. These studies indicate waste distillation costs would be approximately one-third lower than for sea water. Waste distillation costs (including amortization and operation and maintenance) were estimated at approximately $1.00/1,000 gallons for flows less than 1 mgd, and about $0.75/1,000 gallons for flows greater than 10 mgd. The residual total solids would be in the range of 3 to 5 mg/l.

Table 13-II.—RESULTS OF SAMPLES FOR EVALUATING PITCON PROCESS (November 1962)

Location	Total phosphate mg./l as P.	Soluble phosphate mg./l as P.	Nitrate nitrogen mg./l as N.	Nitrite nitrogen mg./l as N.	Ammonia nitrogen mg./l as N.	Organic nitrogen mg./l as N.	Chloride mg./l	ABS mg./l
Influent	9.8	7.2	1.3	0.2	4.0	23.4	33.65	3.90
Effluent	0.4	0.3	----------	1.9	26.5	0.4	33.65	0.01

Biological Methods of Nitrogen Removal

"In the two most common biological treatment methods, the trickling filter and the activated sludge processes, two different reactions are responsible for the decrease in total nitrogen concentration. These are conversion of nitrogen into organic cell material and microbial denitrification. Of the two processes, microbial denitrification is the more important and is largely responsible for the decreases in nitrogen concentration observed in many biological treatment plants (13–15).

"Denitrification refers to that stage of the nitrogen cycle in which nitrates are reduced to gaseous nitrogen. The essential condition for this reaction is anaerobiosis. The first step involves the extension of oxidation in a conventional biological process to the point at which dissolved nitrogen compounds are transformed to nitrite or nitrate. Experience demonstrates that it is relatively easy to operate an activated sludge plant to obtain 90 percent conversion to nitrates. For the second step, denitrification, all necessary conditions are present in normal activated sludges and when such sludges are subjected to anaerobiosis such reduction occurs.

"Wuhrmann (13–16) has performed field experiments on pilot plant scale to investigate the limitations of the process and to establish design criteria. The test units in his investigations were large enough to permit extrapolation to full-size plants. In all experiments sewage of the city of Zurich was used after primary treatment. This sewage was primarily of domestic origin and following primary clarification had a BOD of from 110 to 130 ppm, total nitrogen 25 to 30 ppm, and total phosphorus 4 to 7 ppm. Between the aeration tank and secondary clarifier of a conventional activated sludge plant, an additional basin was placed in which the mixed liquor from the aerator was stored for a short time. In this tank the activated sludge was kept in suspension by a submerged paddle wheel. The detention time was made sufficient to bring the oxygen-containing effluent of the aeration tank to anaerobic conditions and to allow for full denitrification of the nitrates present in the mixed liquor. Anaerobiosis was reached automatically by the respiration of the activated sludge.

"An additional experiment compared the nitrogen elimination in a conventional complete treatment plant with the results accomplished using an identical system with an additional unit for the anaerobic treatment phase. The conventional plant gave an amount of nitrogen elimination in full agreement with experience, i.e., the effluent contained a total nitrogen concentration of 12 to 15 ppm, representing an elimination of 40 to 50 percent (based on settled sewage nitrogen content). The effluent of the denitrification plant showed a very constant low level of nitrogen compounds; there were nitrate ions which had escaped denitrification, and some organic nitrogen in the microorganisms suspended in the final effluent. The BOD values of both plant effluents were almost the same and varied between 6 and 12 ppm.

"In the experiments cited above an additional unit was used for removing phosphorus by precipitation. The final effluent of the denitrification plant was submitted to this treatment. In removing nearly all of the remaining suspended organic solids from the final effluent of the denitrification unit by this precipitation process, the nitrogen concentration was again lowered by 1 to 2 ppm, and consequently an effluent with only about 2 ppm of total nitrogen resulted after phosphate precipitation."

(13–6) Fitzgerald, G. P., "Stripping Effluents of Nutrients by Biological Means," Transactions 1960 Seminar, Taft Sanitary Engineering Center, Technical Rep. W 61–3, 136–139.

(13-7) Parker, C. D., "Microbiological Aspects of Lagoon Treatment," Journal Water Pollution Control Fed., 34, 149–161 (1962).

(13-8) Oswald, W. J., Golneke, C. G., Cooper, R. C., Cree, H. K., and Brenson, J. C., "Water Reclamation, Algal Production and Methane Fermentation in Waste Ponds," Manuscr. No. 25, Int. Conf. Water Pollution Res., London (1962).

(13-9) Nesselson, E. J., "Removal of Inorganic Nitrogen from Sewage Effluents," PhD Thesis, University of Wisconsin (unpublished) (1954).

(13-10) Kuhn, P. A., "Removal of Ammonia Nitrogen from Sewage Effluent," M. S. Thesis, University of Wisconsin (unpublished) (1956).

(13-11) Rohlich, G. A., "Chemical Methods for the Removal of Nitrogen and Phosphorus from Sewage Plant Effluents," Transactions 1960 Seminar, Taft Sanitary Engineering Center, Technical Rep. W61–3, 130–135.

(13-12) Wuhrmann, Karl, private communication to H. Ludwig (6 May 1963).

(13-13) Owen, R., "Removal of Phosphorus from Sewage Effluent with Lime," Sewage and Industrial Wastes, 25, 5, 548 (May 1953).

(13-14) Cornell, Howland, Hayes and Merryfield, "Preliminary Report on a Tertiary Waste Treatment Plant," prepared for the South Tahoe Public Utility District (Jan. 1963).

(13-15) Weinberger, Leon, private communication (1 April 1963).

(13-16) Wuhrmann, K., "Nitrogen Removal in Sewage Treatment Process," XVth Congress of Limnology, Madison, Wisconsin (Aug. 1962).

McIntire, C. D. and C. E. Bond. 1962.

Effects of Artificial Fertilization on Plankton and Benthos Abundance in Four Experimental Ponds. Transactions of the American Fisheries Society, Vol. 91, No. 3, pp. 303–312.

The effects of phosphorus and nitrogen fertilizers on the abundance of fish food organisms were investigated in four newly excavated ponds. Before fertilization the ponds were characterized by low nitrogen and phosphorus concentrations, pH values near neutrality, low total alkalinities, and dissolved oxygen concentrations near saturation. After fertilizers were added to three ponds, chemical and physical conditions were altered considerably by the production of large quantities of plankton organisms. Establishment of plankton populations was followed by development of benthic communities, especially in the two ponds receiving both nitrogen and phosphorus. The benthic community developed most rapidly, and the biomass became greatest in the pond receiving the heaviest applications of nitrogen and phosphorus. In ponds which received no phosphorus, benthic production was low.

McKee, H. S. 1962.
Nitrogen Metabolism in Plants. Clarendon Press, Oxford, England, 728 pp.

Bineau (1865) showed that fresh-water algae used ammonium and nitrate. Chu (1942) found that many planktonic algae including *Oscillatoria rubescens* and several diatoms used both nitrate and ammonium. The only species showing a definite preference for either form of nitrogen was *Botryococcus braunii*, which grew better with nitrate. Most species grew equally well with either nitrate or ammonium at optimum levels of supply, but better with nitrate when the nitrogen supply was restricted. *Chlorella* is reported by Cramer and Meyers (1948) to use ammonium exclusively when nitrate is also available. Absorption of phosphate by the marine diatom *Nitzschia closterium* increased with the nitrate content of the medium, but nitrate absorption was independent of phosphate level (Ketchum, 1939).

Nitrate reduction, being endothermic, must be directly or indirectly coupled with respiration in tissues where this is the only source of energy. Warburg and Negelein (1920) formulated the reduction of nitrate by *Chlorella pyrenoidosa* as follows:

$$HNO_3 + H_2O + 2C = NH_3 + 2CO_2 + 162{,}000 \text{ cal},$$

the carbon being at the oxidation level of carbohydrate.

Nitrogen-fixing species occur in the genera *Anabaena*, *Anabaenopsis*, *Aulosira*, *Calothrix*, *Cylindrospermum*, *Mastigocladus*, *Nostoc*, *Oscillatoria*, and *Tolypothrix* (Fogg and Wolfe, 1954). Some blue-green algae are incapable of fixation. Most species utilize varied nitrogen sources, including ammonia, nitrite, nitrate, amino-acids, and protein. Most species use inorganic sources, but *Synechococcus cedrorum* appears to require organic nitrogen (Allen, 1952). Molybdenum is essential for nitrogen fixation in *Anabaena* and *Nostoc*.

Hausteen (1899) found that the aquatic angiosperm *Lemna* used urea, asparagine, or ammonia, but not nitrate, for protein synthesis in the dark.

The total atmospheric nitrogen reaching the soil per unit area tends to increase with the annual rainfall. The amount of nitrogen reaching the soil as nitrate and ammonium lies usually betwen 2 and 10 kg/ha/year in Europe. Several observers have found appreciable amounts of organically combined nitrogen (usually cited as albuminoid N) in rain. Much of the organic nitrogen of the atmosphere is in small particles such as pollen, spores, bacteria, and dust carried from the earth's surface by ascending currents.

Addition of superphosphate to a small fresh-water lake (Einsele, 1941) led to a substantial increase in its total nitrogen content, presumably through the increased activity of nitrogen-fixing bacteria or blue-green algae. The effect appears analogous to that occurring on land when legume-containing pastures are fertilized with superphosphate.

Bineau, A. 1856. Observations sur l'absorption de l'ammoniaque et des azotates par les végétations cryptogamiques. Ann. Chim. Phys. 3 Sér., Vol. 40, p. 60.

Chu, S. P. 1942. The influence of the mineral composition of the medium on the growth of planktonic algae. Part I. Methods and culture media. Journal of Ecology, Vol. 30, p. 324.

Cramer, M. and J. Meyers. 1948. Nitrate reduction and assimilation in *Chlorella*. J. Gen. Physiol., Vol. 32, p. 93.

Ketchum, B. H. 1939. The Absorption of Phosphate and Nitrate by Illuminated Cultures of *Nitschia closterium*. Amer. J. Bot., Vol. 26, p. 399.

Warburg, O. and E. Negelein. 1920. Über die Reduktion der Salpetersäure in grünen Zellen. Biochem, Z., Vol. 110, p. 66.

Fogg, G. E. and M. Wolfe. 1954. The Nitrogen Metabolism of the Blue-Green Algae (Myxophyceae). In: Autotrophic micro-organisms. Cambridge.

Allen, M. B. 1952. The Cultivation of Myxophyceae. Arch. Mikrobiol., Vol. 17, p. 34.

Hausteen, B. 1899. Über Eiweisssynthese in grünen Phanerogamen. Jb. Wiss. Bot., Vol. 33, p. 417.

Einsele, W. 1941. Die Umsetzung von Zugeführtem, anorganischen Phosphat im eutrophen See und ihre Ruckwirkung auf seinen Gesamthaushalt. Z. Fisch., Vol. 39, p. 407.

McVicker, M. G. L. Bridger, and L. B. Nelson. 1963.
Fertilizer Technology and Usage. Soil Science Society of America, Madison 11, Wisconsin, 464 pp.

Nitrogen consumption as fertilizer in the United States in 1850 was 3,000 tons. In 1950, it was about 1 million tons; in 1960, 3 million tons. Projected figures for 1970 are about 5 million tons. Phosphate consumption in fertilizer has increased steadily from about 390,000 tons of P in 1940 to 1.3 million tons of P in 1960.

Menzel, D. W. and J. P. Spaeth. 1962.
Occurrence of Vitamin B_{12} in the Sargasso Sea. Limnology and Oceanography, Vol. 7, No. 2, pp. 151–154.

The concentration of vitamin B_{12} occurring in Sargasso Sea surface waters during 1960 ranged from undetectable amounts to 0.10 μg/l. Authors suggest that it does not appear likely that B_{12} itself ever directly limits primary production in the Sargasso Sea, but it is quite probable that the concentration of this growth factor exerts a significant and perhaps controlling influence upon the species composition of the phytoplankton.

Meyer, J. and E. Pampfer. 1959.
Nitrogen Content of Rain Water Collected in the Humid Central Congo Basin. Nature, Vol. 184, p. 717.

During April 1958–March 1959, rain water in Yangambi, Belgian Congo, was examined to determine content of inorganic N. Total N brought down by rain was very small; and, contrary to previous assumptions, it appeared to be of doubtful significance for agriculture and for balance of N in arable soil. About 59 percent of total inorganic N in rainfall was ammoniacal N, and nitrous N did not exceed 3 percent of the nitric N. In examination of individual downpours, it was found that the smaller the downpour, the higher the concentration of N, especially of ammoniacal N; and that during heavy downpours concentration of ammonia decreased.

Mikkelsen, D. S., B. A. Krantz, M. D. Miller, and W. E. Martin. 1962.
Cereal Fertilization. California Agricultural Experiment Station Extension Service, University of California Leaflet No. 147.

Results of a series of 221 field tests conducted over 5 years in 38 counties indicate that nitrogen and phosphorus are the nutrients most likely to give response in commercial grain fields. In this group of tests, 32 percent gave significant yield increases from nitrogen alone, 15 percent from phosphorus alone, and 26 percent from a combination of nitrogen-phosphorus treatments. Regrouping these results, 58 percent of these grainland soils were deficient in nitrogen and 42 percent were deficient in phosphorus. Only 25 percent of the tests showed no benefit from fertilization. In a number of areas, experiments indicate that sulfur may also be deficient.

GENERAL GUIDE TO CEREAL FERTILIZATION

Cropping patterns	Rainfall	Fertilizer	
		Nitrogen (N)	Phosphorus[1] (P)
Nonirrigated Grain:	*Inches*	*Pounds per acre*	*Pounds per acre*
Annually cropped	Below 12	0 to 20	7 to 13.
	Above 12	20 to 50	9 to 18.
After fallow	Below 10	None	7 to 9.
	Above 10	10 to 20	7 to 13.
Irrigated:[2]			
Following nonlegume		40 to 100	9 to 35.
Following legume or heavily fertilized crop		0 to 40	9 to 18.
Peat and muck soils		0 to 40	9 to 68.

[1] Where phosphorus needs are determined by soil test or field experience.
[2] On acutely deficient irrigated soils, higher rates may produce optimum yields.

Millar, C. E. 1955.
Soil Fertility. John Wiley and Sons, New York, 436 pp.

The statement that later gave rise to the law of the minimum was issued by Liebig (1849), "by the deficiency or absence of one necessary constituent, all the others being present, the soil is rendered barren for all those crops to the life of which that one constituent is indispensable."

Arnon and Hoagland (In: Soil Sci., 50: 463, 1940) found that tomato plants growing in unaerated culture solutions absorbed smaller quantities of all nutrients than plants in aerated solutions. The limiting influence on nutrient absorption of a low oxygen supply or of a high carbon dioxide content in the growth has been demonstrated by several investigators, and it is established that different plant species vary in their response to given concentrations of the two gases.

The nitrogen content of various plants in percentage of dry matter was given as follows:

	Percent N (dry weight)
Alfalfa:	
Prebud	3.41
In flower	2.06
Kentucky bluegrass:	
Cut every 2 weeks	2.83
Cut when in bloom	1.72
Rye:	
10–14 inches high	2.50
Mature plant	0.24

Nitrogen in the soil varies with texture. In black clay loams, the nitrogen in the upper 6⅔ inches of soil was 7,230 pounds per acre; brown silt loams, 5,035; brown loams, 4,720; brown sandy loams, 3,070; yellow fine sandy loams, 2,170; and sand plains and dunes, 1,440.

The nitrogen, phosphorus, and potassium contents of average yields of a number of crops including corn, oats, barley, rye, wheat, and potatoes ranges from 18- to 78-N, 3- to 12-P, and 10- to 100-K pounds per acre, respectively.

The highest, lowest, and average number of pounds of nitrogen found in a ton of mixed manure are reported by Van Slyke (1932) to be 16, 8, and 10, respectively. Of the animal manures, that from poultry is the highest in nitrogen content with 1.0 to 1.5 percent; sheep manure contains about 0.9 to 1.0 percent.

The total quantity of nitrogen brought to the earth in precipitation varies from around 2 to about 20 pounds per acre per year. The average for localities not very close to cities or industrial sites has been found to be around 4 to 6 pounds.

The phosphorus content of the surface 6⅔ inches of 11 sandy loams, 19 loams, 24 silt loams, and 19 silty clay loams in Iowa was 864, 1,205, 1,288, and 3,089 pounds per acre, respectively.

The pounds of fertilizer recommended for different crops in various geographical regions were given as follows:

Region	Pounds per acre of					
	Grassland		Corn		Wheat	Cotton
Northeast	[1]30	450	[1]254	450	300	-----
Cornbelt	[1]14	150	[1]80	175	250	300
Appalachian	[1]63	300	[1]285	300	400	600
Southeast	[1]73	450	[1]290	300	400	600
Delta	[1]62	275	[1]118	300	-----	475
Southern plains	[1]8	80	[1]38	175	70	175
Northern plains	[1].4	50	[1]8	50	50	-----
Mountain	[1]1.3	50	[1]11	100	70	130
Pacific	[1]6.1	50	[1]36	75	50	100

[1] Used, 1950.

The quantities of manure excreted by 1,000 pounds of live weight of different animals and the nutrient content of the manure were given as follows:

Animal	Pounds excreted per year	Dry matter pounds per year	Pounds nitrogen	Pounds phosphorus
Horse	18,000	3,960	128	19
Cow	27,000	3,780	156	17
Swine	30,600	3,978	150	45
Sheep	12,600	4,032	119	43
Poultry	8,600	3,870	85	68

Average farm manure as applied to the field contains approximately 10 pounds of nitrogen, and 2.2 pounds of phosphorus per ton.

Liebig, J. 1849. Chemistry and its Relation to Agriculture and Physiology. John Wiley and Sons, New York.

Van Slyke, L. L. 1932. Fertilizers and Crop Production. Orange Judd Publishing Co., New York.

Miller, R. B. 1961.

The Chemical Composition of Rain Water at Taita, New Zealand, 1956–58. New Zealand Journal of Science, Vol. 4, p. 844.

Rain water was collected monthly for 3 years at Taita Experimental Station of New Zealand Soil Bureau near Wellington, and analyzed for main elements present. The salt found, excluding bicarbonate, was about 190 pounds per acre per year, of which nearly 80 percent was sodium chloride; significant amounts of sulfate and magnesium were also present, and phosphate was very low (less than 1 pound per acre per year). Total nitrogen was measured in some of the samples and was found to be about double the concentration of inorganic and albuminoid nitrogen; contributions from rain water to nitrogen in soil would probably be not less than 3 pounds per acre per year. Ionic ratios showed that in periods of southerly storms salt tended to approach composition of sea water, and at other times calcium and potassium (and to lesser degree magnesium and sulfate) reached high proportions.

Moore, H. B. 1958.
Marine Ecology. John Wiley and Sons, Inc., New York, 493 pp.

Phosphorus may be present in the form of either organic or inorganic compounds, and both in particulate form and in solution. Within living tissues it is present mainly in organic compounds, and it is released back into the water by their excretions and decay in either particulate or soluble form. There is evidence that some organic phosphorus compounds can be utilized by algae, but most of it is broken down to phosphate by bacterial action, and then utilized as such by the algae. Riley et al. (1949) are cited as assuming the critical level for phosphate to be at a concentration of 0.55 mg.-atoms of phosphorus per cubic meter in the productivity of plankton populations. Rohde (1948) found that the optimal concentration of phosphate for growth varied in different species of algae and that a given concentration might be optimal for one, sub-optimal for another, and supraoptimal for yet another.

Allee et al. (1949) are cited as giving the amount fixed by the action of lightening and falling as nitrate on one sq. km. of ocean surface as 175 kg. per year.

Allee, W. C., A. E. Emerson, O. Park, T. Park, and K. P. Schmitt. 1949.
Principles of Animal Ecology, Saunders, Philadelphia, pp. 1–837.

Riley, G. A., H. Stommel, and D. F. Bumpus. 1949.
Quantitative Ecology of the Plankton of the Western North Atlantic. Bull. Bingham Oceanog. Coll., Vol. 12, No. 3, pp. 1–169.

Rohde, W. 1948.
Environmental Requirements of Fresh-water Plankton Algae. Symbolae Botan. Upsalinenses, Vol. 10, pp. 1–149.

Moyle, J. B. 1956.
Relationships between the Chemistry of Minnesota Surface Waters and Wildlife Management. Jour. Wildlife Management, Vol. 20, No. 3, pp. 302–320.

The author reasons that the size of population of mixed fish is related to the water fertility and conditions associated with it and that the structure of a fish population adjusts itself until it consists of those species that can best utilize a specific degree of fertility and conditions associated with it. A relationship was found between the total phosphorus concentration and the standing crop of fishes in Minnesota surface waters. On the basis of surveys it was estimated that Mississippi headwater lakes support about 90 pounds of fish per acre; the summer surface waters of these lakes have a mean total phosphorus content of about 0.034 mg/l. In central Minnesota the mean total phosphorus content of fish lakes is 0.058 mg/l, and the average fish production capacity is estimated at 150 pounds per acre. In southern Minnesota, the total phosphorus content is 0.126 mg/l; seining in 40 fish lakes showed an average standing crop of 280 pounds of rough fish per acre plus about 90 pounds of other fishes, a total of 370 pounds per acre.

Müller, W. 1953.

Nitrogen Content and Pollution of Streams. Gesundheitsing, Vol. 74, p. 256; Water Pollution Abstracts, Vol. 28, No. 2, Abs. No. 454.

The author concludes that excessive growths of plants and algae in polluted waters can be avoided if the concentration of nitrate nitrogen is kept below about 0.3 mg/l and the concentration of total nitrogen is not allowed to rise much above 0.6 mg/l.

Neess, J. C. 1949.

Development and Status of Pond Fertilization in Central Europe. Transactions American Fisheries Society, Vol. 76 (1946), pp. 335–358.

Phosphorus is undoubtedly the most important single fertilizer. It has frequently appeared to assume the role of limiting factor. Phosphorus may be removed from solution by a number of mechanisms which do not act independently of one another. In alkaline waters where there is an excess of calcium, phosphorus may precipitate as tricalcium phosphate [$Ca_3(PO_4)_2$]. This salt is converted to the more soluble di- and mono-calcium phosphates as the pH of the water is reduced. In the presence of iron, insoluble ferric phosphate may be formed. In addition, it may be adsorbed directly on organic soil colloids (humus) whose nature is not clearly understood. Under these circumstances, phosphorus will tend to accumulate in the bottom in insoluble forms where it is not available to the phytoplankton in general, although some algae may be able to use adsorbed phosphorus more or less directly. Bacteria can use particulate phosphorus in a microzone surrounding the cell and thus the element may be passed on through food chains. Increased solubility of strongly basic phosphates may be the result of local acidity from base-exchange. Beneath the surface of the soil where oxidation-reduction potentials are lowered, collidal complexes of ferric iron are made soluble by reduction and phosphorus adsorbed on them is released.

Neil, J. H. 1957.
Problems and Control of Unnatural Fertilization of Lake Waters. Engineering Bulletin, Proceedings of the Twelfth Industrial Waste Conference, Purdue University, pp. 301–316.

In one of the first plant-scale experiments in the removal of phosphorus from a primary sewage treatment plant by chemical precipitation using a combination of alum and activated silica, soluble phosphorus was reduced by about 98 percent and combined phosphorus by 81 percent. That which was lost was contained as fines of the floc or particulate matter which did not settle. In addition to the improvements noted for phosphorus, a 35 percent reduction in Kjeldahl nitrogen was noted.

The average sewage flow was 1.27 mgd and contained 166 pounds of phosphorus per million gallons. The average concentrations of alum and silica applied were 94.0 mg/l and 3.4 mg/l, respectively. The cost of alum, silica, soda, and trucking per million gallons of sewage was $25.75.

In the two years before chemical precipitation was begun, the average soluble phosphate content in the river one-half mile downstream from the disposal plant was 0.6 mg/l. During the period that continuous precipitation was applied, the average soluble phosphate concentration dropped to 0.05 mg/l.

Odum, E. P. in collaboration with H. T. Odum. 1959.
Fundamentals of Ecology. W. B. Saunders Company, Philadelphia, 546 pp.

Turnover rate is a fraction of the total amount of a substance in a component which is released (or which enters) in a given length of time. Turnover time is the reciprocal of this, the time required to replace a quantity of substances equal to the amount in the component. For example, if 1,000 units are present in the component and 10 go out or enter each hour, the turnover rate is 10/1,000 or 0.01 per hour. Turnover time would then be 1,000/10 or 100 hours.

Basic or primary productivity of an ecological system is defined as the rate at which energy is stored by photosynthetic and chemosynthetic activity of producer organisms (chiefly green plants) in the form of organic substances which can be used as food materials. Gross primary productivity is the total rate of photosynthesis including the organic matter used up in respiration during the measurement period. Net primary productivity is the rate of storage of organic matter in plant tissue in excess of the respiratory utilization by the plants during the period of measurement. Gross primary productivity, net primary, and secondary productivity of various ecosystems are recorded by Odum in the following tables:

Gross primary productivity of various ecosystems as determined by gas exchange measurements of intact systems in nature

Ecosystem	Rate of production gms/M²/day
Averages for long periods—6 months to 1 year:	
Infertile open ocean, Sargasso Sea [1]	0.5
Shallow, inshore waters, Long Island Sound; year average [3]	3.2
Texas estuaries, Laguna Madre [4]	4.4
Clear, deep (oligotrophic) lake, Wisconsin [5]	.7
Shallow (eutrophic) lake, Japan [6]	2.1
Bog lake, Cedar Bog Lake, Minnesota (phytoplankton only) [7]	.3
Lake Erie, winter [8]	1.0
Lake Erie, summer [8]	9.0
Silver Springs, Florida [9]	17.5
Coral reefs, average three Pacific reefs [10]	18.2
Values obtained for short favorable periods:	
Fertilized pond, N.C. in May [11]	5.0
Pond with treated sewage wastes, Denmark, July [12]	9.0
Pond with untreated wastes, South Dakota, summer [13]	27
Silver Springs, Florida, May [9]	35
Turbid river, suspended clay, N.C., summer [11]	1.7
Polluted stream, Indiana, summer [14]	57
Estuaries, Texas [4]	23
Marine turtle-grass flats, Florida, August [14]	34
Mass algae culture, extra CO_2 added [15]	43

[1] Riley (1957). [3] Riley (1956). [4] H. T. Odum (unpublished). [5] Juday (1940). [6] Hogetsu and Ichimura (1954). [7] Lindeman (1942). [8] Verduin (1956). [9] H. T. Odum (1957). [10] Kohn and Helfrich (1957). [11] Hoskin, 1957 (unpublished). [12] Steeman-Nielsen (1955). [13] Bartsch and Allum (1957). [14] H. T. Odum (1957a). [15] Tamiya (1957).

Annual net primary productivity of various cultivated and natural ecosystems as determined by use of harvest methods

Ecosystem	Net primary production grams per square meter	
	Per year	Per day
Cultivated crops:[1]		
Wheat, world average	344	0.94 *(2.3)
Wheat, average in area of highest yields (Netherlands)	1,250	3.43 (8.3)
Oats, world average	359	.98 (2.4)
Oats, average in area of highest yields (Denmark)	926	2.54 (6.2)
Corn, world average	412	1.13 (2.3)
Corn, average in area of highest yields (Canada)	790	2.16 (4.4)
Rice, world average	497	1.36 (2.7)
Rice, average in area of highest yields (Italy and Japan)	1,440	3.95 (8.0)
Hay, U.S. average	420	1.15 (2.3)
Hay, average in area of highest yields (California)	940	2.58 (5.2)
Potatoes, world average	385	1.10 (2.6)
Potatoes, average in area of highest yields (Netherlands)	845	2.31 (5.6)
Sugarbeets, world average	765	2.10 (4.3)
Sugarbeets, average in area of highest yields (Netherlands)	1,470	4.03 (8.2)
Sugarcane, world average	1,725	4.73 (4.7)
Sugarcane, average Hawaii	3,430	9.40 (9.4)
Sugarcane, maximum Hawaii under intensive culture [2]	6,700	18.35 (18.4)
Mass algae culture, best yields under intensive culture outdoors, Tokyo [3]	4,530	12.4 (12.4)
Noncultivated ecosystems:		
Giant ragweed, fertile bottomland, Oklahoma [4]	1,440	3.95 (9.6)
Tall Spartina salt marsh, Georgia [5]	3,300	9.0 (9.0)
Forest, pine plantation, average during years of most rapid growth (20-35 years old), England [6]	2,180	6.0 (6.0)
Forest, deciduous plantation, England, comparable to the above pine plantation [7]	1,560	3.0 (6.0)
Tall grass prairies, Oklahoma and Nebraska [8]	446	1.22 (3.0)
Short grass grassland, 13 in. rainfall; Wyoming [9]	69	.19 (.5)
Desert, 5 inches rainfall, Nevada [10]	40	.11 (.2)
Seaweed beds, Nova Scotia [11]	358	1.98 (1.0)

*Values in parenthesis are rates for growing season only, which is often less than a year.

[1] Values for crops obtained from Woytinsky (1953) and from 1957 U.S. Government "Statistical Abstracts" and corrected to include dry weight of unharvested parts of plant and to exclude water in case of crops such as potatoes, sugarcane, etc., which are harvested "wet." All averages are for several post-war years.

[2] Based on Burr, et al. (1957) who gives dry weight data on an exceptionally large crop. [3] Tamiya (1957). [4] Penfound (1956). [5] E. P. Odum & Smalley (1957). [6] Ovington (1957). [7] Ovington & Pearsall (1956). [8] Penfound (1956) and Weaver (1954). [9] Lang & Barnes (1942). [10] E. P. Odum (unpublished). [11] MacFarlane (1952).

Secondary productivity as measured in fish production

Ecosystem and trophic level	Man's harvest	
	Gms per M² per year	Pounds per acre per year
I. UNFERTILIZED NATURAL WATERS		
Herbivore-carnivore composition:		
North Sea [1]	1.68	15.
World marine fishery (average) [2]	0.05	0.45.
Great Lakes [3]	0.09 to 0.82	0.80 to 7.3.
African lakes [1]	0.16 to 25.2	1.40 to 225.
U.S. small lakes (sports fishery) [4]	0.21 to 18.1	1.90 to 162.
Stocked carnivores: U.S. fish ponds (sports fishery) [1]	4.5 to 16.8	40 to 150.
Stocked herbivores: German fish ponds (carp) [6]	11.2 to 39.0	100 to 348.
II. FERTILIZED WATERS		
Stocked carnivores: U.S. fish ponds (sports fishery) [1, 5]	22.4 to 56.0	200 to 500.
Stocked herbivores:		
Philippine marine ponds [1]	50.4 to 101.0	450 to 900.
German fish ponds (carp) [6]	99.7 to 157.0	890 to 1,400.
III. FERTILIZED WATERS AND OUTSIDE FOOD ADDED		
Carnivores: 1-acre pond, United States [5]	227.0	2,027.
Herbivores:		
Hongkong [1]	224.0 to 448.0	2,000 to 4,000.
South China [1, 6]	112.0 to 1,540.0	1,000 to 13,500 (average 4,000).
Malaya [1]	392	3,500.

[1] Hickling (1948). [2] Cutting (1952). [3] Rawson (1952). [4] Rounsefell (1946). [5] Swingle and Smith (1947). [6] Viosca (1935).

Bartsch, A. F. and Allum, M. O. 1957. Biological factors in the treatment of raw sewage in artificial ponds. Limnol. and Oceanogr., 2: 77–84.

Burr, G. O., Hartt, H. E., Brodie, H. W., Tanimoto, T., Kortschak, H. P. Takahashi, D., Ashton, F. M., and Coleman, R. E. 1957. The sugar cane plant. Ann. Rev. Plant. Physiol., 8: 275–308.

Cutting, C. L., 1952. Economic aspects of utilization of fish. Biochem. Soc. Symposium No. 6. Biochemical Society. Cambridge, England.

Hickling, C. F., 1948. Fish farming in the Middle and Far East. Nature, 161: 748–751.

Hogetsu, K., and Ichimura, S. 1954. Studies on the biological production of Lake Suwa. VI. The ecological studies on the production of phytoplankton. Japanese J. Bot., 14: 280–303.

Juday, Chancey. 1940. The annual energy budget of an inland lake. Ecol., 21: 438–450.

Kohn, A. J., and Helfrich, P. 1957. Primary organic productivity of a Hawaiian Coral Reef. Limnol. and Oceanogr., 2: 241–251.

Lang, R., and Barnes, O. K. 1942. Range forage production in relation to time and frequency of harvesting. Wyo. Agr. Exp. Sta. Bull. No. 253.

Lindeman, R. L. 1941. Seasonal food-cycle dynamics in a senescent lake. Am. Midl. Nat., 26: 636–673.

MacFarlane, Constance. 1952. A survey of certain seaweeds of commercial importance in southwest Nova Scotia. Canadian J. Bot., 30: 78–97.

Odum, E. P. and Smalley, A. E. 1957. Trophic structure and productivity of a salt marsh ecosystem. Progress report to Nat. Sc. Foundation (mimeo).

Odum, H. T. 1957. Trophic structure and productivity of Silver Springs, Florida. Ecol. Monogr., 27: 55–112.

Odum, H. T. 1957a. Primary production measurement in eleven Florida springs and a marine turtle-grass community. Limnol. and Oceanogr., 2: 85–97.

Ovington, J. D., and Pearsall, W. H. 1956. Production Ecology. II. Estimates of average production by trees. Oikos, 7: 202–205.

Ovington, J. D. 1957. Dry matter production by *Pinus sylvestris*. Annals Bot. n.s., 21: 287–314.

Penfound, W. T. 1956. Primary production of vascular aquatic plants. Limnol. and Oceanogr., 1: 92–101.

Rawson, D. S. 1952. Mean depth and the fish production of large lakes. Ecol., 33: 513–521.

Riley, G. A. 1956. Oceanography of Long Island Sound, 1952–54. IX. Production and utilization of organic matter. Bull. Bingham Oceanographic Coll., 15–324–344.

Riley, G. A. 1957. Phytoplankton of the north central Sargasso Sea. Limnol. and Oceanogr., 2: 252–270.

Rounsefell, G. A. 1946. Fish production in lakes as a guide for estimating production in proposed reservoirs. Copeia, 1946: 29–40.

Steemann-Nielson, E. 1955. The production of organic matter by phytoplankton in a Danish lake receiving extraordinary amounts of nutrient salts. Hydrobiologia, 7: 68–74.

Swingle, H. S., and Smith, E. V. 1947. Management of farm fish ponds (Rev. Ed.). Alabama Polytechnic Inst. Ag. Exp. Sta. Bull. No. 254.

Tamiya, Hiroshi. 1957. Mass culture of algae. Ann. Rev. Plant Physiol., 8: 309–334.

Verduin, Jacob. 1956. Primary production in lakes. Limnol. and Oceanogr., 1: 85–91.

Viosca, Percy, Jr. 1935. Statistics on the productivity of inland waters, the master key to better fish culture. Tr. Am. Fish Soc., 65: 350–358.

Weaver, J. E. 1954. North American Prairie. Johnsen Publ. Co., Lincoln, Nebraska.

Woytinsky, W. S., and Woytinsky, E. S. 1953. World Population and Production. The Twentieth Century Fund, New York.

Ohle, W. 1953.

Phosphorus as the Initial Factor in the Development of Eutrophic Waters.

Vom Wasser, Vol. 20, pp. 11–23; Water Pollution Abstracts, Vol. 28, No. 4, Abs. No. 893.

When oxygen is present at the surface of the sediment in a lake, iron phosphate and iron hydroxide are formed and dissolved phosphate is absorbed. The pH value of the sludge is generally between 6 and 7, at which value absorption of phosphate by ferric hydroxide is active. Experiments showed that maximum absorption takes place at pH 5.9 and there is a decrease above and below this value.

Sewage treatment by sedimentation and percolating filters was found to have little effect on the total phosphorus concentratiton.

It appears that the nitrogen demand of both oligotrophic and eutrophic waters can be satisfied under natural conditions but the natural supply of phosphate is small and the optimum amount for vigorous algal growth is only reached by addition of wastes. Phosphate must thus be regarded as the initial factor in the development of eutrophic conditions.

Overbeck, J. 1961.
The Phosphatase of *Scenedesmus quadricauda* and their Ecological Importance.
Verh. Int. Ver. Limnol. 1959, Vol. 14, pp. 226–231; Water Pollution Abstracts, Vol. 35, No. 8, Abs. No. 1497.

Determinations of inorganic and total dissolved phosphorus in the water of an artificial pond, which was refilled at regular intervals with water from the river Havel, showed a concentration of over 5 mg/l phosphorus, mainly present in the combined form. Experiments, using *Scenedesmus quadricauda*, were made to determine to what extent the combined phosphorus could be utilized by algae. Phosphorus was taken up immediately from potassium phosphate, to a small extent from sodium pyrophosphate, and not at all from sodium glycerophosphate, calcium phyate, and sodium nucleinate. By addition of a bacterial suspension, phosphate was enzymatically released from sodium glycerophosphate and made available to the alga. It was concluded that the strain of *Scenedesmus quadricauda* used could utilize combined phosphorus only through the intervention of water bacteria.

Owen, R. 1953.
Removal of Phosphorus from Sewage Plant Effluent with Lime.
Sewage and Industrial Wastes, Vol. 25, No. 5, pp. 548–556.

Analysis of samples of domestic sewage from communities in Minnesota, with populations varying from 1,200 to 940,000, showed that the raw sewage of these communities contained 1.5 to 3.7 grams, with a median of 2.3 grams of phosphorus per capita per day (1.9 pounds per year). The amount of phosphorus removed by sewage treatment varied from 2 to 46 percent with an average of 23 percent. Laboratory and pilot plant studies showed that phosphorus could be "almost completely" removed by adding lime in controlled dosages to an effluent after mixing and allowing the resulting precipitate to settle under quiescent conditions. Removals of phosphorus from 6 ppm to 0.015 ppm were obtained under laboratory conditions and from 7.4 ppm to 1.7 ppm under plant-scale tests. Cost would approximate $7,600 per year for 0.5 mgd of sewage treated with unslaked lime.

Paloumpis, A. A. and W. C. Starrett. 1960.
An Ecological Study of Benthic Organisms in Three Illinois River Flood Plain Lakes. American Midland Naturalist, Vol. 64, No. 2, pp. 406–435.

The authors consider wild duck nutrient contributions to 3,500-acre Lake Chautauqua in Illinois. Since domestic ducks are fed large quantities of prepared feeds by man, their wastes would be expected to be higher in nutrients than those of wild ducks. Therefore, a factor of 0.5 was used to determine that the annual nutrient contribution to Lake Chautauqua resulting from the wild duck population was 12.8 pounds of total nitrogen (N), 5.6 pounds of total phosphorus (P), and 2.6 pounds of soluble phosphorus per acre of water.

Parker, C. D. 1962.
Microbiological Aspects of Lagoon Treatment. Journal Water Pollution Control Federation, Vol. 34, No. 2, pp. 149–161.

High algal populations are uniformly present in unicell aerobic stabilization ponds, but are much more variable and are at a lower level in multicell ponds. By the use of multicell ponds in series it is possible to obtain relatively clear effluents free from objectionable algal turbidity. In the multicell aerobic ponds there was a steady reduction in count from pond to pond irrespective of the number of algae present. There appears to be no evidence to support the view that the release of bactericidal substances from algal material is responsible for the reduction in count.

In aerobic unicellular ponds with detention times ranging from 10 to 37 days the algal counts ranged from 2.2×10^6 to 8.36×10^6, respectively. In aerobic multicell stabilization ponds (8 cells in series), under summer conditions the following nutrient and algal conditions were noted:

	Raw Sewage	Ponds							
		1	2	3	4	5	6	7	8
Org.-N (mg./l.)	26.3	12.5	14.5	11.2	13.7	16.4	8.9	8.1	7.8
NH_3-N (mg./l.)	22.4	48.4	32.5	48.7	45.6	42.5	40.0	28.1	18.9
NO_3-N (mg./l.)	0	0	0	.3	.5	.2	.5	.2	.8
Algae (No./ml.)	Nil	7×10^6	7.1×10^6	2.4×10^7	1.4×10^7	1.2×10^6	7.2×10^6	2.9×10^6	8.5×10^6

No mention is made of the length of time that the ponds have been in operation.

Phinney, H. K. and C. A. Peek. 1961.
Klamath Lake, an Instance of Natural Enrichment. Algae and Metropolitan Wastes, U.S. Public Health Service, SEC TR W61-3, pp. 22-27.

For at least 60 years the algal populations of Upper Klamath Lake have been sufficiently large to cause comment and speculation as to the cause and effects of the growth. The prime offender in the summer bloom has been *Aphanizomenon*. Partial analysis of freshly dried algae showed 61.1 percent crude protein, 5.73 percent ash, and 0.60 percent phosphorus. ". . . there are no inorganic chemical constituents that could be singled out as being responsible for this condition" [algal production]. It was the authors' belief that the action of the humates as chelating and buffering agents was primarily responsible for the observed stimulation.

Pomeroy, L. R., H. M. Mathews and H. S. Min. 1963.
Excretion of Phosphate and Soluble Organic Phosphorus Compounds of Zooplankton. Limnology and Oceanography, Vol. 8, p. 55.

The amount of phosphorus excreted daily by marine zooplankton has been found to be nearly equal to its total phosphorus content, slightly more than half excreted phosphorus was phosphate and remainder was soluble organic phosphorus. It was suggested that phosphorus excreted by zooplankton may constitute a significant fraction of that required by phytoplankton for photosynthesis.

Porges, R. and K. M. Mackenthun. 1963.
Waste Stabilization Ponds: Use, Function, and Biota. Biotechnology and Bioengineering, Vol. 5, pp. 255-273.

Photosynthesis and its dependence upon the algal mass, suitable temperature, incident light penetration, nutrient supply, and induced vertical mixing by wind are of prime importance in the stabilization mechanism. Odors are associated with prolonged anaerobic conditions, and these may persist up to 4 weeks following extended ice cover in cold climates, if BOD loadings are 25 lbs. per acre per day or greater. Nitrogen and carbon may be limiting factors in the development of an algal mass. A striking similarity exists generally among the algal speciation in stabilization ponds, regardless of geographic location. The algal mass is, however, dependent upon unique pond conditions and location, and may vary upwards to nearly 5 million algal cells per milliliter, 34,000 ppm by volume, or 30–35 tons per acre per year.

Nutrients, because of their potential for creating biological nuisance growths, are becoming increasingly important as factors to be considered in the discharge of wastes or treated effluents. Under climatic conditions found in Wisconsin, organic nitrogen formed the bulk of the total nitrogen in the stabilization pond, with the exception of high (30 mg. per liter) wintertime concentrations under ice when the ammonia nitrogen increased until it made up nearly 80 percent of the total nitrogen. Removals were as low as 6 percent in winter and 80–90 percent in summer. Phosphorus concentrations were lowest in summer and fall and highest in late winter. There was no phosphorus reduction through the stabilization pond in winter. Summertime reductions ranged from 58 to 80 percent or higher, dependent upon loading. At the Fayette, Missouri, installation nitrogen reduction was found to be 94–98 percent and phosphorus reduction, 83–92 percent (Neel et al., 1961).

Neel, J. K., J. H. McDermott, and C. A. Monday, Jr., 1961. Experimental Lagooning of Raw Sewage at Fayette, Missouri. Journal Water Pollution Control Federation, Vol. 33, No. 6, pp. 603–641.

7

Pratt, D. M. 1950.
Experimental Study of the Phosphorus Cycle in Fertilized Salt Water. Sears Foundation: Journal of Marine Research, Vol. 9, No. 1, pp. 29–54.

The rates at which phosphorus is (1) assimilated by phytoplankton, (2) released into solution from dead cells, and (3) regenerated to inorganic state, were measured in outdoor concrete tanks containing sea water fertilized with inorganic phosphate and nitrate. Bottles wrapped in black cloth and bottles exposed to the light were filled with the tank water and suspended in the tanks; the three rates in the P cycle were calculated from the observed changes in the concentrations of inorganic and particulate P in the bottles. The maximum recorded rates were: assimilation=0.36 μg-at. P/l of sea water in the tanks/day; solution=0.38 μg-at./l/day; regeneration=0.13 μg-at./l/day. In 18 series of measurements, during which phytoplankton increases predominated over decreases, the following relations were observed between the rates of phosphorus transformations and the size and absolute change of size of the phytoplankton populations: (1) The rate of phosphorus assimilation was significantly correlated with the size of the phytoplankton standing crop and showed an even stronger dependence upon the increment of growth. (2) The rate at which particulate organic phosphorus was released into solution was intimately related to the size of the standing crop and was independent of the change in population size (which in most cases was an increase). (3) The regeneration of dissolved inorganic phosphate from dissolved organic phosphorus depended upon the phytoplankton standing crop and showed no relation to the change in population size. If attached algae were allowed to grow on the sides and bottom of the tanks, in less than one month they removed three-fourths of the added phosphate from the water-phytoplankton system. Where attached algae were largely prevented from growing, four-fifths of the phosphorus originally present was detected in the water at the end of four weeks.

Prescott, G. W. 1960.
Biological Disturbances Resulting from Algal Populations in Standing Waters. The Ecology of Algae, Spec. Pub. No. 2, Pymatuning Laboratory of Field Biology, University of Pittsburgh, pp. 22–37 (1959).

Of all the nutritive elements and dissolved substances known to be used by algae, those which are most often critical are phosphorus and nitrogen. When these nutrients are present in unusual quantities, a lake can support tremendous populations of algae that recur year after year. Algal distrubances occur in relatively shallow lakes where it is possible for nitrates and phosphates to be recirculated from bottom decomposition. Excessive and troublesome growths can occur only in lakes which are amply supplied with CO_2 or with bicarbonates from which carbon dioxide necessary for photosynthesis can be extracted.

Most likely the response of some species by producing bloom populations, and no such response from other species, is related in part to the high reproductive rate possessed by particular plants. The reproductive rate is usually paralleled by the speed with which nutrients are absorbed.

The protoplasm of most blue-green algal species is highly proteinaceous. Crude protein analyses (dry weight) show that *Microcystis aeruginosa* is 55.58 percent protein; *Anabaena flos-aquae* is 60.56 percent and *Aphanizomenon flos-aquae* is 62.8 percent. Hence their requirement for nitrates for the elaboration of proteins is much greater than that of green algae such as *Spirogyra*, for example, which is 23.82 percent protein, or *Cladophora*, 23.56 percent. Nitrogen alone in *Aphanizomenon* amounts to 10.05 percent (dry weight) as compared with 3.81 percent in *Spirogyra*.

It has been demonstrated in laboratory cultures and inferred from numerous water and plankton analyses that phosphorus is more critical than nitrogen in determining phytoplankton production. Atkins (1923) found that 1.12 mg of P_2O_5 was used to produce 1×10^9

diatoms during the first phase of growth. One gram of P_2O_5 suffices for 9×10^{11} diatoms. Atkins (1923, 1925) found that in the sea one liter of water can produce 26.8 million diatoms for each 0.03 mg. of P consumed.

Plankton populations in eutrophic lakes where electrolytes are abundant are characteristically greater than in oligotrophic lakes where electrolytes and CO_2 content are low. Rawson (1953) measured 10 to 14 Kg of plankton per hectare in Canadian oligotrophic lakes as compared with 100 Kg per hectare in eutrophic lakes. He refers to Lake Mendota (Wisconsin) in which Birge and Juday measured 177 Kg of plankton per hectare.

Atkins, W. R. G. 1923. Phosphate Content of Water in Relationship to Growth of Algal Plankton. Journal Marine Biological Association, U. K. Vol. 13, pp. 119–150.

Atkins, W. R. G. 1925. Seasonal Changes in the Phosphate Content of Sea Water in Relation to the Growth of Algal Plankton during 1923 and 1924. Journal Marine Biological Association, U. K., Vol. 13, pp. 700–720.

Provasoli, L. 1961.
Micronutrients and Heterotrophy as Possible Factors in Bloom Production in Natural Waters. Algae and Metropolitan Wastes, U.S. Public Health Service, SEC TR W61–3, pp. 48–56.

Of 154 algal species, 56 require no vitamins and 98 species require vitamin B_{12}, thiamin and biotin, alone or in various combinations. Those blue-green algae not requiring B_{12} employ it readily as a cobalt source; since cobalt is generally scarce in water, even organisms not requiring B_{12} may compete for it. A great part of the vitamins in fresh-waters and in the littoral zone of the sea can be assumed to come from any soil run-off especially during the spring floods. Muds are another source of vitamins. A third source is the vitamins present as solutes in water. Fungi and many bacteria also produce B_{12}.

Provasoli, L. 1963.
Organic Regulation of Phytoplankton Fertility. In: The Sea, Vol. 2, The Composition of Sea-Water, Comparative and Descriptive Oceanography, M. N. Hill, General Editor, Interscience Publishers, N.Y., pp. 165–219.

Birge and Juday (1934), in grouping the data from several hundred lakes according to total organic carbon, found a C/N ratio of 12.2 for lakes containing 1.0 to 1.9 mg C/1. In the North Atlantic deep waters of similar C content a C/N ratio from 2.5 to 6.5 with a mean of 2.7 has been found.

Extra-cellular nitrogenous products have been noted frequently in cultures of bacteria or blue-green algae fixing nitrogen. As much as 50 percent of the total nitrogen taken up by *Anabaena cylindrica* was excreted during the early logarithmic growth; 10 to 20 percent at half growth; and moribund material liberates large quantities of soluble organic nitrogen (Fogg, 1952). The extra-cellular nitrogenous substances may or may not serve as nutrients to other organisms.

The important nutritional characteristics of the environment for phytoplankton include nitrogen, phosphorus, vitamins and trace metals. It seems probable that in inshore waters B_{12} is rarely limiting and not a constraint on fertility. But when the quantities of B_{12}-like cobalamins are far lower, as in the open sea, the specificity of the various algae toward the different cobalamins may be decisive.

Birge, E. A. and C. Juday, 1934. Particulate and Dissolved Organic Matter in Inland Lakes. Ecological Monographs, Vol. 4, pp. 440–474.

Fogg, G. E. 1952. The Production of Extracellular Nitrogenous Substances by a Blue-green alga. Proceedings Royal Society of London, B 139, pp. 372–397.

Provasoli, L. and I. J. Pintner. 1960.

Artificial Media for Fresh-water Algae: Problems and Suggestions. The Ecology of Algae, Spec. Pub. No. 2, Pymatuning Laboratory of Field Biology, University of Pittsburgh, pp. 84–96 (1959).

Most algae utilize nitrates except the euglenoids which, so far as is known, prefer ammonia or amino acids. Ten to 20 mg. percent nitrates are in general well tolerated. Ammonia tends to become toxic above 3 to 5 mg. % in alkaline media except for eurybionts living in polluted water. Mineral phosphates should be avoided because they cause precipitates, especially in alkaline media. Glycerophosphates have been found adequate in concentrations of 0.5 to 3 mg.%.

Provost, M. W. 1958.

Chironomids and Lake Nutrients in Florida. Sewage and Industrial Wastes, Vol. 30, No. 11, pp. 1417–1419.

Florida has experienced an increasing problem with "blind mosquitoes" (*Glyptotendipes paripes*). Preliminary investigation showed that the heaviest midge producing lakes were those likely to receive the most inorganic nutrients, providing that the right kind of bottom was present. A larval control method using water-wettable BHC applied in the wake of a motorboat was developed; however, the midge larvae developed sufficient tolerance to BHC to make lake treatment ineffective. Results of further study revealed EPN to be a good larvacide, but this was effective only a year and a half during which the midge larvae developed a resistance. No control concentrations were stated.

Putnam, H. D. and T. A. Olson. 1959.
A Preliminary Investigation of Nutrients in Western Lake Superior 1958–1959. School of Public Health, University of Minnesota, 32 pp. (Mimeo.)

Analyses of surface and subsurface samples from Lake Superior showed that ammonia nitrogen was present in trace amounts only, usually less than 0.1 mg/1. Low concentrations of organic nitrogen were present in Lake Superior throughout the year but persisted at a higher level in the epilimnion than in deeper layers. The range was from 0.08 mg/1 in the hypolimnion to 0.28 mg/1 at the surface. The bulk of the nitrogen in the lake existed in the form of nitrate and ranged from 0.93 mg/1 at the surface to 1.15 mg/1 in the hypolimnion. Nitrite was practically undetectable.

Seventy to 100 percent of the phosphorus in Lake Superior appears to be present in the organic form. Values ranged from 0.18 to 0.46 microgram atoms of total phosphorus per liter.

The water that enters Lake Superior from its tributary streams contains very little free ammonia. The highest value, 0.1 mg/1, was obtained on August 12 in the Amnicon River. Nitrate concentrations in the rivers were lower than that observed in the lake and varied from 0.16 mg/1 to 0.47 mg/1. Nitrite was absent or present only in trace amounts.

Total phosphorus levels in the streams were higher than those observed in the lake. In August the concentration of phosphorus along the north shore varied from 1.0 in the Poplar River to 1.46 microgram atoms per liter in the Baptism River. On the south shore the Brule River contained 1.70 microgram atoms which was the maximum for August.

Putnam, H. D. and T. A. Olson. 1960.
An Investigation of Nutrients in Western Lake Superior. School of Public Health, University of Minnesota, 24 pp. (mimeo.)

In more than two-thirds of the samples from Lake Superior it was found that the nitrate nitrogen concentrations were directly related to the depth of the sample and in no case was the concentration lower in the deeper water layers than near the surface. Concentrations of NO_3-N varied from 0.28 to 0.36 mg/l at the surface and from 0.32 to 0.47 mg/l below the thermocline. Only traces of ammonia and nitrite were found in the lake water during the 1958 investigation and were not included in the 1959 study.

The nitrate nitrogen in all streams, except one, was considerably lower than that observed in the lake. In August, the range was 0.01 to 0.44 mg/l. The overall mean total phosphorus concentration for north shore streams was 0.72 microgram atom per liter while that for the south shore tributaries was 1.36 microgram atoms per liter. Inorganic phosphorus constituted 38.5 percent of the total value (1.56 μg at/l) in the St. Louis River, and 67.0 percent of the total phosphorus concentration in the Black River (3.0 μg at/l).

Rainwater from selected points within the Duluth area contained significant levels of nitrogen but only traces of other nutrient materials. The ammonia concentration ranged from 0.24 to 0.59 mg/l. Reduction of the ammonia level from 0.59 to 0.20 mg/l in samples from two consecutive days suggested that nitrogen was washed from the atmosphere rather quickly. Organic nitrogen ranged from 0.26 to 0.60 mg/l; 0.22 mg/l nitrate was found in one sample.

Redfield, A. C., B. H. Ketchum and F. A. Richards. 1963.
The Influence of Organisms on the Composition of Sea-Water. In: The Sea, Vol. 2, The Composition of Sea-Water, Comparative and Descriptive Oceanography, M. N. Hill, General Editor, Interscience Publishers, N.Y., pp. 26–77.

The proportions in which the elements of sea-water enter into the biochemical cycle is determined by the elementary composition of the biomass. Atomic ratios of the principal elements present in plankton are as follows:

	Carbon	Nitrogen	Phosphorus
Zooplankton	103	16.5	1
Phytoplankton	108	15.5	1
Average	106	16	1

It has been demonstrated repeatedly in culture experiments that the elementary composition of unicellular algae can be varied by changing the composition of the medium in which they grow. If one element is markedly deficient in the medium, relative to its need by the organism, cell growths and cell division can proceed for a limited period of time. The cells produced under these conditions contain less of the deficient element than do normal cells. When an element is provided in excess in the medium, luxury consumption can increase its content in the cells. Experimental variation of the C : N : P ratios (by atoms) in culture of the freshwater alga *Chlorella pyrenoidosa* (after data of Ketchum and Redfield, 1949) were given as follows:

Condition	C	N	P
Normal cells	17	5.6	1
Phosphorus deficient cells	231	30.9	1
Nitrogen deficient cells	75	2.9	1

Liebig's law of the minimum implies that in a growth of a crop of plants, when other factors such as light and temperature are favorable, the nutrient available in the smallest quantity relative to the requirement of the plant will limit the crop. Nitrogen and phosphorus appear to occur in sea-water in just the proportions in which they are utilized by the plankton, a fact first noted by Harvey (1926).

	Availability in "average" sea-water		Utilization by plankton
	mg A/m^3	ratio	ratio
Phosphorus	2.3	1	1
Nitrogen	34.5	15	16
Carbon	2,340	1,017	106

Rythor (1960) has estimated that the plankton of oceans as a whole contains 3 g/m^2 carbon. Assuming this to be concentrated in the upper 100 m, the wet weight of plankton in the water would be equivalent to about 1 part in 3 million.

Harvey, H. W. 1926. Nitrate in the Sea. J. Mar. Bio. Assoc. U. K., n. s., Vol. 14, pp. 71–88.

Ketchum, B. H. and A. C. Redfield. 1949. Some Physical and Chemical Characteristics of Algae Grown in Mass Culture. J. Cell. Comp. Physiol., Vol. 33, pp. 281–300.

Ryther, J. H. 1960. Organic Production by Planktonic Algae and its Environmental Control. The Pymatuning Symposium in Ecology. Pymatuning Laboratory of Field Biology, University of Pittsburgh, Special Pub. No. 2, pp. 72–83.

Rice, T. R. 1953.
Phosphorus Exchange in Marine Phytoplankton.
Fish and Wildlife Service, Fishery Bulletin #80, pp. 77–89.

The author cites Ketchum (1939a) as showing that *Nitzschia* cells absorb more phosphorus when grown in medium containing high phosphorus concentrations. Since the amount of phosphorus entering the cells is proportional to the concentration in the medium, it necessarily follows that any phosphorus entering the cell in excess of that which the cell can convert into the organic state, will remain in the inorganic state. Ketchum (1939b) has shown that phosphate-deficient cells contain only a small fraction of the phosphorus found in nondeficient cells, and that more phosphorus is absorbed by deficient cells when again placed in medium containing phosphorus. Rice showed that phosphate-deficient cells grown in low concentrations of phosphorus absorbed more phosphorus than nondeficient cells grown in a similar concentration of phosphorus. It was assumed that the metabolic rate of the phosphate-deficient cells was higher than that of the nondeficient cells. Cells grown in the high concentration of phosphorus absorbed more phosphorus than those grown in the low concentration. The high concentration contained 1,137.5 μg At P/l and the low concentration contained 45.5 μg At P/l. Ketchum (1939b) has shown that nondeficient cells will not absorb phosphorus from medium in the dark and phosphate-deficient cells placed in the dark will continue to absorb phosphate only for about 10 hours. In experiments performed by Rice, cells kept in the dark converted very little intracellular inorganic phosphorus into the organic state.

Two ways in which phosphorus may enter a cell are discussed by Kamen and Spiegelman (1948). One method is believed to be diffusion through the cell membrane of phosphorus as inorganic orthophosphate to combine with the intracellular orthophosphate. Inorganic orthophosphate is assumed to be the source of phosphorus for the various organic phosphates in the cell. The other method is the entry of phosphorus into the cell through esterification at the cellular interface. Intracellular inorganic orthophosphate would then arise primarily from the breakdown of organic phosphate. From their experimental data with yeast these investigators concluded that the primary mechanism of the entrance of phosphate is by esterification.

Kamen, M. D. and S. Spiegelman. 1948
Studies on the Phosphate Metabolism of Some Unicellular Organisms. Cold Spring Harbor Symposia on Quantitative Biology, Vol. 13, pp. 151–163.

Ketchum, B. H. 1939a.
The Absorption of Phosphate and Nitrate by Illuminated Cultures of *Nitzschia closterium.* Amer. Journ. Bot., Vol. 26, pp. 399–407.

Ketchum, B. H. 1939b.
The Development and Restoration of Deficiencies in the Phosphorus and Nitrogen Composition of Unicellular Plants.
Jour. Cell. and Comp. Physiol., Vol. 13, pp. 373–381.

Rickett, H. W. 1922.

A Quantitative Study of the Larger Aquatic Plants of Lake Mendota. Trans. Wisconsin Acad. Sci., Arts, Letters, Vol. 20, pp. 501–522.

In Lake Mendota, Wisconsin, the 0- to 1-meter zone contained 1,600 pounds of submerged plants per acre on a dry weight basis; the 1- to 3-meter zone, 2,400 pounds; and the 3- to 7-meter zone, 1,300 pounds.

Rickett, H. W. 1924.
A Quantitative Study of the Larger Aquatic Plants of Green Lake, Wisconsin. Trans. Wisconsin Acad. Sci., Arts, Letters, Vol. 21, pp. 381–414.

Plants were collected at the time of flowering from a ½ meter square iron frame with the aid of a diving hood. The average yield from Green Lake was as follows:

Depth	Pounds per acre	
	Wet	Dry
0–1 meter	4,550	600
1–3 meter	15,440	1,960
3–8 meter	14,380	1,880
All depths	13,540	1,590

The downward limit of plant growth appeared to be controlled by the transmission of 1 percent of the surface incident light.

Rigler, F. H. 1956.
A Tracer Study of the Phosphorus Cycle in Lake Water. Ecology, Vol. 37, pp. 550–562; Water Pollution Abstracts, Vol. 29, No. 11, Abs. No. 1850.

Using radioactive phosphorus a study was made of the phosphorus cycle in a small acid bog in Ontario. Of the total concentration of phorphorus-32 added to the surface of the water, 77 percent was lost from the water to plankton in 4 weeks, but only 2 percent was lost through the outlet from the lake and only 3 percent to the bottom mud. It was concluded that there was a turn-over of "mobile" phosphorus of the epilimnion with the phosphorus of the littoral organisms, this exchange taking 3.5 days. Several days after the addition of phosphorus-32 to a lake, 50 percent had passed into the fraction of plankton recovered by a Foerst centrifuge. When complete removal of plankton was achieved by filtering water through a Millipore filter, it was found that over 95 percent of the added phosphorus-32 was taken up by plankton within 20 minutes. The turn-over period of inorganic phosphate in the surface water of the lake was approximately 5 minutes. Under natural conditions, the turn-over of phosphate appeared to be caused primarily by bacteria, and it was concluded that aquatic bacteria might compete with algae for inorganic phosphate.

Rigler, F. H. 1964.

The Phosphorus Fractions and the Turnover Time of Inorganic Phosphorus in Different Types of Lakes. Limnology and Oceanography, Vol. 9, No. 4, pp. 511–518.

Soluble phosphorus in the trophogenic zone of lakes occurs in the inorganic form as orthophosphate and in a soluble organic phosphorus form. That inorganic phosphorus is readily used is beyond dispute. The orthophosphate in the trophogenic zone of lakes is continually taken up and released by plankton, the turnover time of this fraction being as short as 3.6 minutes (Rigler, 1956).

Using a Millipore filter with pore diameter of 0.45 μ to separate seston from the water, the mean percentage of the total phosphorus of epilimnetic water for 8 Ontario lakes was 5.9 percent for the inorganic fraction, 28.7 percent for the soluble organic fraction, and 65.4 percent for the seston fraction. This compares to 9.5, 28.5, and 62 percent, respectively, found by Hutchinson (1957) for Linsley Pond, Connecticut. The average turnover time of dissolved inorganic P ranged from 1.9 to 7.5 minutes in summer and from 7 to 10,000 minutes in winter for the 8 Ontario lakes. The Ontario lakes ranged in area from 0.5 to 2,180 hectares, and in depth from 6 to 53 meters. The fraction of the total phosphorus that can accurately be described as soluble organic P is still unknown. Half of the phosphorus described as soluble organic may be neither soluble nor colloidal, but associated with particles between 0.1 μ and 0.45 μ diameter.

Hutchinson, G. E. 1957. A Treatise on Limnology, Volume I, 1015 pp.

Rigler, F. H. 1956. A Tracer Study of the Phosphorus Cycle in Lake Water. Ecology, Vol. 37, pp. 550–562.

Rodale, J. I. (Editor), 1960.

The Complete Book of Composting. Rodale Books, Inc., Emmaus, Pa., 1007 pp.

The percentage nitrogen and phosphoric acid composition of various materials was given as follows:

Material	Percentage	
	N	P_2O_5
Apple leaves, fresh	1.00	0.15
Apple skins, ash		3.08
Cantaloupe rinds, ash		9.77
Cattail reed and water lily stems	2.02	.81
Cattle manure, fresh	.29	.17
Duck manure, fresh	1.12	1.44
Fish scraps, fresh	6.50	3.75
Milk	.50	.30
Potato tubers, fresh	.35	.15
Potato skins, raw (ash)		5.18
Seaweed (Atlantic City)	1.68	.75
Sewage sludge, fresh	2.00	1.90
Sludge, activated, heat treated	5.00	3.25
Sweet potato skins, boiled (ash)		3.29

Dried manures contain amounts up to 5 times higher in nitrogen and phosphoric acid.

The chemical composition of certain sewage sludges was given as follows: (Analyses were on a moisture-free basis)

Activated sludges	Percentages	
	Nitrogen (N) Total	Phosphoric acid (P_2O_5) total
Chicago, Ill.	4.81	6.86
Chicago, Ill.	5.60	6.97
Houston, Tex.	5.77	3.08
McKeesport, Pa.	5.62	7.30
Milwaukee, Wis.	5.96	2.96

Rohlich, G. A. 1961.

Chemical Methods for the Removal of Nitrogen and Phosphorus from Sewage Plant Effluents. Algae and Metropolitan Wastes, U.S. Public Health Service, SEC TR W61-3, pp. 130-135.

Laboratory studies show it is possible to remove approximately 96 to 99 percent of the soluble phosphates from the effluent of a sewage treatment plant. This removal can be accomplished in a coagulation process employing any of the following coagulants: (a) aluminum sulfate, (b) ferrous sulfate, (c) ferric sulfate, or (d) copper sulfate.

Filter alum appears to be the most suitable coagulant because: (a) The residual phosphate concentration of the effluent following coagulation with 200 ppm of alum is, on the average, 0.06 ppm, expressed as P. (b) The optimum pH range for the removal of phosphates through coagulation with alum is 7.1 to 7.7. (c) The concentration of aluminum hydroxide in the effluent of the coagulation process is approximately 1.0 to 1.5 ppm and represents a loss of only 0.75 percent of the coagulant. (d) The aluminum hydroxide floc resulting from the hydrolysis of alum may be recovered, purified by removing the absorbed phosphates in the form of tricalcium phosphate, and re-used for further phosphorus removal in the form of sodium aluminate. This recovery and purification reduces by 80 percent the cost of chemicals required to remove phosphates from sewage treatment plant effluent.

Pilot plant studies show that with the use of the alum recovery process, from 77 to 89 percent of the soluble phosphates can be removed. Filtering of the effluent showed that from 93 to 97 percent of the soluble phosphate can be removed. Improved settling facilities should give phosphorus removals that lie between the unfiltered and filtered values obtained in the pilot plant study.

Much less attention has been given to the removal of nitrogen from sewage and sewage effluent by chemical means obviously because soluble nitrogen compounds are least affected by precipitation processes.

Rudolfs, W. 1947.
Phosphates in Sewage and Sludge Treatment. Sewage Works Journal, Vol. 19, No. 1, p. 43.

An average phosphate concentration in raw sewage of 2.3 mg/l as P was reported. The range was 1.7 to 4.0 mg/l as P. The average concentration in effluents from biological treatment was 0.22 mg/l as P. The indicated per capita phosphate—P contributions from domestic raw sewage were 0.53 to 1.20 pounds per year. Settling removed 50 to 60 percent; filtration, 75 to 80 percent; and activated sludge, 80 to 90 percent.

Ryther, J. H. 1963.
Geographic Variations in Productivity. In: The Sea, Vol. 2, The Composition of Sea-water, Comparative and Descriptive Oceanography, M. N. Hill, General Editor, Interscience Publishers, N. Y., pp. 347–380.

Rich fertile soil contains about 5 percent organic humus and as much as 0.5 percent nitrogen. This and the accompanying nutrients in a cubic meter of rich soil, together with atmospherically supplied carbon, hydrogen and oxygen, can support a crop of some 50 kg of dry organic matter, an amount equivalent to more than 200 tons per acre of soil 3 feet deep. Under optimal conditions plants are capable of converting the solar energy falling on a square meter of surface to an organic yield of the order of 10 g/day in excess of their own metabolic requirements. If terrestrial plants can sink their roots into 3 feet of rich soil, they have access, then, to enough nutrients to grow at their maximum potential rate for periods of several to many years.

The richest ocean water, exclusive of local polluted areas, contains about 60 μg atoms/l, or 0.00005 percent nitrogen. A cubic meter of this sea-water could support a crop of no more than about 5 g of dry organic matter.

According to Riley, 1951, a 100-meter euphotic zone contains nitrogen at a concentration of about 15 μg atoms per liter and represents a reservoir of 21 g of nitrogen in a 1-m^2 column. Thus, the relationships between chlorophyll, standing crop of organic matter, transparency, organic production and nitrogen availability and requirements were given as follows:

Chl. a g/l	Standing crop mg/m³ dry wt.	Depth euphotic zone, m	Calc. org Prod., g dry wt. m²/day	N initially available in euphotic zone, mg	N required to produce existing population mg	N requirement, mg/day
0	0	120	0	25,200	0	0
0.1	10	65	0.20	13,000	65	30
0.5	50	36	0.50	7,900	180	60
1.0	100	24	0.75	5,000	290	75
2.0	200	15	1.00	3,100	380	100
5.0	500	10	1.40	2,100	550	140
10.0	1,000	6	1.90	1,200	650	180
20.0	2,000	3.5	2.20	735	700	220

By the time a phytoplankton crop of 2 g/m³ has developed, the euphotic zone is limited to 3.5 m and the nitrogen in the water is exhausted.

Riley, G. A. 1951. Oxygen phosphate, and nitrate in the Atlantic Ocean. Bull. Bingham Oceanog. Coll., Vol. 13, pp. 1–126.

Sanderson, W. W. 1953.
Studies of the Character and Treatment of Wastes from Duck Farms. Proc. 8th Ind. Waste Conf., Purdue Univ. Ext. Ser., Vol. 83, pp. 170–176.

The raw wastes produced daily by 1,000 domestic ducks contained an average of 5.7 pounds of total nitrogen (N), 7.6 pounds of total phosphate (PO_4), and 3.6 pounds of soluble phosphate. Each domestic duck annually contributes 2.1 pounds of total nitrogen (N), 0.9 pound of total phosphorus (P), and 0.4 pound of soluble phosphorus.

Sattelmacher, P. G. 1962.
Methemoglobinemia from Nitrates in Drinking Water. Schriftenreihe des Vereins fur Wasser—Boden-und Lufthygiene, No. 20, 35 pp.

After considering 249 references, it is the author's opinion that the limiting value in drinking water for nitrate (NO_3) should be 30 mg/l.

Saunby, T. 1953.
Soilless Culture. Transatlantic Arts Inc., New York, 104 pp.

For many years soilless culture has been employed in the study of plant physiology, but during recent years this method of growing plants has been adopted by commercial and amateur growers as a means of producing crops of high yields and quality cheaply and cleanly. The basic nutrient solution for soilless culture contains 130 mg/l N, 120 mg/l K_2O, 100 mg/l P_2O_5, 40 mg/l MgO, and 3 mg/l Fe. When the solution is compounded from sodium nitrate, potassium sulfate, superphosphate 16% P_2O_5, magnesium sulfate and ferrous sulfate, the following quantities are required:

Sodium nitrate	13½ ounces.	Magnesium sulfate	4 ounces.
Potassium sulfate	4 ounces.	Ferrous sulfate	¼ ounce.
Superphosphate 16 percent P_2O_5	10 ounces.	Water to	100 gallons.

Sawyer, C. N. 1947.
Fertilization of Lakes by Agricultural and Urban Drainage. Journ. New England Water Works Assn., Vol. 61, No. 2, pp. 109–127.

Ammonia nitrogen is the most important nitrogen stimulant to explosive algal growths (compared with nitrate nitrogen) and may be a factor in determining the type of bloom produced. All the evidence obtained in the Madison survey lends support to the belief that phosphorus is a key element in determining the biological activity in a body of water. ". . . Nuisance [algal] conditions can be expected when the concentration of inorganic phosphorus exceeds or equals 0.01 ppm." A critical level of 0.30 mg/l of inorganic nitrogen was indicated.

Agricultural drainage in the Madison, Wisconsin, area was found to contribute approximately 4,500 pounds of nitrogen and 225 pounds of phosphorus per square mile of drainage area per year. Biologically treated sewage was found to supply approximately 6.0 pounds of nitrogen and 1.2 pounds of phosphorus per capita per year. The lakes at Madison downstream from the city were found to be fertilized by nitrogen in amounts ranging from 127 to 588 pounds per acre per year and by phosphorus in amounts ranging from 19.0 to 88.6 pounds per acre per year. The lakes retained 30.4 to 60.5 percent of the nitrogen they received. These lakes were rich producers of nuisance blue-green algal blooms.

Sawyer, C. N. 1952.
Some New Aspects of Phosphates in Relation to Lake Fertilization. Sewage and Industrial Wastes, Vol. 24, No. 6, pp. 768–776.

In analyzing data from 17 lakes in southern Wisconsin with respect to biological behavior, the conclusion is reached that concentrations in excess of 0.01 mg/l of inorganic phosphorus and 0.30 mg/l of inorganic nitrogen at the time of spring overturn could be expected to produce algal blooms of such density as to cause nuisance. Laboratory experiments were performed with one source of natural water:

Mixture with lake water	Period (days)	Total nitrogen (mg/l)		
		Start	Finish	Gain
Control	167	0.51	2.61	2.10
10 percent sewage effluent added	181	2.67	4.39	1.72
10 percent effluent minus N and P	170	.67	2.17	1.50
10 percent effluent minus N	188	.67	11.85	11.81

"From the fact that a heavy growth of blue-green algae did occur in the presence of a plentiful supply of phosphorus and a deficiency of nitrogen and that nitrogen was simultaneously fixed from the atmosphere, it may be concluded that phosphorus is a key element in the fertilization of natural bodies of water and that any deficiency of nitrogen can be obtained from the atmosphere." Author quotes Rudolfs (1947) who reported on the removal of phosphates from sewage by coagulation with lime and found that the total soluble phosphorus content could be reduced to about 0.5 mg/l by lime treatment. Ferric salts and aluminum sulfate have been proposed for coagulation of phosphates from sewage (Sawyer, 1944); both coagulants are highly effective but the coagulant requirements are markedly increased by the amount of phosphate present. Alum has been proposed by Lea and Rohlich (1950) as the most suitable coagulant because the aluminum can be recovered from the sludge by treatment with caustic to form sodium aluminate which is re-usable.

Ordinarily domestic sewages contain from 15 to 35 mg/l of nitrogen and from 2 to 4 mg/l of phosphorus. A large percentage of these fertilizing elements exist in a readily available condition or become so during biological treatment or while undergoing stabilization by microorganisms in the receiving body of water.

Rudolfs, W. 1947. Phosphates in Sewage and Sludge Treatment. I. Quantities of Phosphates. Sewage Works Journal, Vol. 19, No. 1, pp. 43-47.

Sawyer, C. N. 1944. Biological Engineering in Sewage Treatment. Sewage Works Journal, Vol. 16, No. 5, pp. 925-935.

Lea, W. L. and G. A. Rohlich, 1950. Phosphate Removal by Coagulation. Paper read before Div. of Water, Sewage, and Sanitation Chem., ACS Detroit Meeting.

Sawyer, C. N. 1954.

Factors Involved in Disposal of Sewage Effluents to Lakes. Sewage and Industrial Wastes, Vol. 26, No. 3, pp. 317-325.

When the "cash in the bank" assets of inorganic nitrogen and phosphorus exceed 0.30 and 0.01 mg/l respectively, at the start of the active growing season, a season with nuisance blooms may be anticipated.

Several factors affecting lake biological productivity are cited. Lake area becomes a critical factor because of the tendency of blue-green odor-producing nuisance algae to float, thus large lakes often have a bad history even with relatively light inflows of nutrients. The shape of the lake determines in some degree the amount of fertilizing matter it can safely assimilate. A round lake with minimum dimensions would provide the least opportunity for the collection of floating algae, whereas one with a long wind sweep would provide greater opportunity for accumulation. Prevailing winds and wind intensity are important factors as is the depth-area-volume relationship.

Sawyer, C. N. and A. F. Ferullo. 1961.
Nitrogen Fixation in Natural Waters under Controlled Laboratory Conditions. Algae and Metropolitan Wastes, U.S. Public Health Service, SEC TR W61–3, pp. 100–103.

In the laboratory studies, no attempt was made to ascertain whether nitrogen fixation was due to algal or bacterial action. It seems important to note, however, that whenever unusual amounts of nitrogen were fixed, blue-green algae were found in the test specimens. The dominant genus noted was *Aphanizomenon*. It was concluded that: (1) phosphorus is a key element in nitrogen fixation, (2) fertilization of aquatic areas by domestic wastes stimulates biological productivity, (3) sewage plant effluents contain phosphorus in excessive amounts, (4) the excess phosphorus can stimulate extensive blooms of nitrogen fixing blue-green algae, and (5) the productivity of most aquatic areas is probably related to their phosphorus budgets.

Sawyer, C. N., J. B. Lackey, and R. T. Lenz. 1945.
An Investigation of the Odor Nuisances Occurring in the Madison Lakes, Particularly Monona, Waubesa and Kegonsa from July 1942–July 1944. Report of Governor's Committee, Madison, Wisconsin, 2 Vols. (Mimeo.)

The average annual concentration of inorganic nitrogen in the effluent of 17 southeastern Wisconsin lakes ranged from 0.10 mg/l in oligotrophic Rock and Geneva lakes to 0.79 mg/l in highly eutrophic Waubesa Lake that was receiving the treated sewage effluent from Madison, Wisconsin. Highest inorganic nitrogen concentrations in the latter body of water occurred in February and March (1.15 and 1.24 mg/l, respectively). The average annual inorganic phosphorus concentration in the same lakes ranged from <0.01 mg/l in 8 of the lakes to 0.38 in Lake Waubesa.

Schuette, H. A. 1918.
A Biochemical Study of the Plankton of Lake Mendota. Trans. Wisconsin Acad., Sci., Arts, Letters, Vol. 19, pp. 594–613.

Analyses were made of composite plankton samples obtained by pumping up water from different levels of the lake and straining it through a plankton net. In 7 samples, total nitrogen ranged from 4.51 to 9.94 percent dry weight with an average of 7.55 percent while the available protein nitrogen ranged from 2.82 to 8.67 percent and averaged 4.55 percent. Forty to 87 percent of the total nitrogen was in the available form. Total phosphorus ranged from 0.92 to 1.57 percent and averaged 1.26 percent.

Schuette, H. A. and H. Alder. 1928.
Notes on the Chemical Composition of Some of the Larger Aquatic Plants of Lake Mendota. II *Vallisneria* and *Potamogeton*. Trans. Wisconsin Acad. Sci., Arts, Letters, Vol. 23, pp. 249–254.

Plants were hand-picked, air-dried, and desiccated at 60° C.

	Sand-free basis	
	Vallisneria	Potamogeton
	Percent	*Percent*
Ash	25.19	11.42
Total nitrogen (N)	1.88	1.28
Total phosphorus (P)	.23	.18

Schuette, H. A. and H. Alder. 1929a.
Notes on the Chemical Composition of Some of the Larger Aquatic Plants of Lake Mendota. III *Castalia odorata* and *Najas flexilis*. Trans. Wisconsin Acad. Sci., Arts, Letters, Vol. 24, pp. 135–139.

	Castalia	Najas
	Percent	*Percent*
Ash	11.21	19.16
Total nitrogen (N)	2.78	1.66
Total phosphorus (P)	.27	.30

Schuette, H. A. and H. Alder. 1929b.
A Note on the Chemical Composition of Chara from Green Lake, Wisconsin. Trans. Wisconsin Acad. Sci., Arts, Letters, Vol. 24, pp. 141–145.

Ash, 41.22 percent; total nitrogen, 0.72 percent to 4.50 percent; total phosphorus, 0.06 percent. (Sand-free basis.)

Stumm, W. and J. J. Morgan. 1962.
Stream Pollution by Algal Nutrients. Twelfth Annual Conference on Sanitary Engineering, University of Kansas, pp. 16–26. (Harvard University Sanitary Engineering Reprint No. 45.)

Present day aerobic biological treatment mineralizes substantial fractions of bacterially oxidizable organic substances but is not capable of eliminating more than 20 to 50 percent of nitrogenous and phosphatic constituents.

The P-content of domestic sewage is about 3 to 4 times what it was before the advent of synthetic detergents, and it is not unlikely that the P-content of sewage may continue to rise. Since the ability to assimilate elementary nitrogen by certain blue-green algae has been demonstrated to be of importance in fresh water, phosphorus is a key element in the fertilization of natural bodies of water. If phosphorus (as P) is the predominant limiting factor, 1 mg of phosphate (as P) released to the surface water in one single pass of the phosphorus cycle is capable of accompanying the production of about 75 mg of organic material.

Assuming a sustained annual net algal production of 5 gm/m^2/day in a stabilization pond, the required pond area for the autotrophic stripping of 7 mg P/1 in a sewage flow of 1 mgd (corresponding to roughly 10,000 inhabitants) would be 100 acres. Harvesting of the algal crop would be necessary for efficient nutrient removal.

Swingle, H. S. and E. V. Smith. 1939.
Fertilizers for Increasing the Natural Food for Fish in Ponds. Trans. American Fisheries Soc., Vol. 68, pp. 126–135.

In pond waters a 4:2:1:8 ratio of N-P-K-$CaCO_3$ (mixture of commercial fertilizer) gave a fish production of 578 pounds per acre compared to 134 pounds per acre in the unfertilized control. The amounts of commercial fertilizers used per acre per application were: 40 pounds sulfate of ammonia, 60 pounds superphosphate (16 percent), 5 pounds muriate of potash, and 30 pounds basic slag (or 15 pounds $CaCO_3$).

Sylvester, R. O. 1961.
Nutrient Content of Drainage Water from Forested, Urban and Agricultural Areas. Algae and Metropolitan Wastes, U.S. Public Health Service, SEC TR W61–3, pp. 80–87.

Nutrient data are presented from major highways, arterial and residential streets anywhere from 30 minutes to several hours after a rainstorm had commenced;* from three streams containing large reservoirs, roads and some logging but no human habitation as they emerge from forested areas;** from the Yakima River Basin irrigation return flow drains,*** and from Green Lake**** in Washington.

Mean nutrient concentrations (ppb)

	Total phosphorus (P)	Soluble phosphorus (P)	Nitrates (N)	Total kjeldahl nitrogen (N)
Urban street drainage*	206	76	527	2,010
Urban street drainage (median)*	154	22	430	410
Streams from forested areas**	69	7	130	74
Subsurface irrigation drains***	216	184	2,690	172
Surface irrigation drains***	251	162	1,250	205
Green Lake****	76	16	84	340

"Nuisance algal blooms were observed to commence in Seattle's Green Lake (a very soft-water lake) when nitrate nitrogen levels were generally above 200 ppb and soluble phosphorus was greater than 10 ppb."

Sylvester, R. O. and G. C. Anderson. 1964.
A Lake's Response to its Environment. Journal of the Sanitary Engineering Division, ASCE, Vol. 90, No. SA1, pp. 1–22 (February).

Two-hundred-fifty-six acre Green Lake in Seattle, Washington, has an unusually wide diversification of recreational use that has been retarded by seasonal algal blooms, littoral vegetation, and outbreaks of swimmer's itch. Samples of fresh and aged wild fowl excrement were found to average 1.43 milligrams of nitrates, 10.3 milligrams of organic nitrogen, and 0.91 milligram total phosphorus. Bottom sediments were analyzed; decomposition of organic matter is brought about by bacterial action, but a significant fraction remains and, as the sediments are built up yearly, the underlying fraction is sealed off and further degradation ceases. The uppermost layer of bottom mud was found to contain 1.67 milligrams total phosphorus (P) per gram (parts per billion) of dry solids, 7.0 milligrams total nitrogen (N) per gram of dry solids, 8.94 percent solids of wet weight, and 27.6 percent volatile solids (dry weight). C. H. Mortimer was credited with finding that in aerated tank water or in a lake, well supplied with dissolved oxygen, the exchange of solutes and nutrients between mud and water was slight. As oxygen depletion continued in water overlying mud, reducing conditions began in the mud, and solutes were released in increasing quantities to the overlying water. "A yearly catch of 100,000 trout, each averaging about 0.3 lb, would contain about 292 mg P per 100 g of fish for a total of 88 lb per year of P removed in the fish catch." The total P input was 4.8 pounds per surface acre and 55 percent annually was retained in the lake.

Sylvester, R. O. and R. W. Seabloom. 1963.
Quality and Significance of Irrigation Return Flow. Journal of the Irrigation and Drainage Division, ASCE, Vol. 89, No. IR3, Proc. Paper 3624, pp. 1–27 (September).

A study was made of irrigation return flow in the Yakima River Basin, Washington, for an irrigated area of 375,280 acres during an irrigation season whose principal months extend from April through September. Average water diversion was 6.6 acre-feet per acre per year of which approximately 4.25 acre-feet per acre was applied to land, the remainder being lost in canal seepage, canal evaporation, and wastage. The evapo-transpiration loss in itself would result in a salt concentration increase of 1.7 times in the irrigation return water. Chemical constituent increases occurring in the subsurface drainage water because of evapo-transpiration, leaching and ion exchange, expressed as number of times greater than in the applied water were as follows: bicarbonate alkalinity, 4.8; chlorides, 12; nitrate, 10; and soluble phosphate, 3.2. During the irrigation and nonirrigation seasons, the approximate contribution of ions or salts in pounds per acre resulting from irrigation were, respectively, bicarbonate, 575 and 715; chloride, 37 and 63; nitrate, 33 and 35; and soluble phosphate, 1 and 1.2.

Tamm, C. O. 1951.
Removal of Plant Nutrients from Tree Crowns by Rain. Physiologia Plantarum, Vol. 4, pp. 184–188. (From Putnam and Olson, 1960.)

The study area was the experimental forest of the Forest Research Institute, Bogesund, Sweden.

Analysis of pure rainwater samples collected in an open area in October and November provided the following data:

Organic matter	3 to 10 mg/l.	Sodium	0.4 to 0.7 mg/l.
Calcium	0.4 to 0.6 mg/l.	Total nitrogen	0.2 mg/l.
Potassium	0.2 mg/l.	Phosphorus	0.03 mg/l.

Tamm, C. O. 1953.

Growth, Yield, and Nutrition in Carpets of a Forest Moss. Meddelanden från Statens Skogsforskning Institut, Vol. 43, pp. 1–140. (From Putnam and Olson, 1960.)

Rainwater was collected in an open field using funnels and flasks of stainless steel. Analysis of the collected rainwater yielded the following data (mg/l):

	NH_3-N	P	K	Na	Ca	Fe	Mn	SiO_2
Nov. 1–17, 1951	0.8	0.1	0.6	1.0	0.7	0.02	0	0.4
Nov. 17–24, 1951	.2	.1	.3	.7	.2	.02	0	--------
July 17–Aug. 12, 1952	.9	--------	.3	.3	.5	--------	--------	--------
Aug. 12, 15, 1952	.5	--------	.3	.5	.2	--------	--------	--------

During the summer and autumn of 1952, rainwater was collected during five different periods, using glass funnels and flasks. A total of 227 mm of water fell during the sampling period carrying down, as an average from three different sampling vessels, 0.97 mg K, 1.41 mg Na, and 0.91 mg Ca per dm^2.

Tanner, H. A. 1960.

Some Consequences of Adding Fertilizer to Five Michigan Trout Lakes. Transactions American Fisheries Society, Vol. 89, No. 2, pp. 198–205.

Inorganic fertilizer (10–6–4) was applied to four of a group of six Michigan trout lakes ranging in size from 2.6 to 5.9 acres at rates varying from 80 to 650 pounds per acre. The thermocline in the three lakes receiving the most fertilizer shifted to a more shallow position. Three of the fertilized lakes decreased in total alkalinity at a greater rate than did the two lakes not fertilized. Fertilization resulted in the oxygen being depleted from the hypolimnion and some oxygen reduction occurred in the thermocline. The volume of oxygenated water remaining under the ice during the critical period of late winter was reduced in the fertilized lakes, and lakes fertilized at the highest rate very nearly approached winterkill conditions. The reduction of oxygen both in summer stagnation periods and in late winter was more severe after the second season of fertilization. Author cites Einsele (1938) as indicating that, in general, when iron is present in the hypolimnion, it combines with phosphorus as ferric phosphate in the presence of oxygen. The precipitate formed is insoluble and results in the removal of phosphorus from the lake water. If, however, oxygen is absent when the iron and phosphorus combine, the product is a soluble ferrous phosphate, some of which will be reused. Mortimer (1941) has indicated that the processes of reduction usually return the nutrient material in forms more usable by plants and bacteria than do the processes of oxidation. Eutrophication is extremely slow while the lake is oligotrophic. When the lake assumes the characteristics of a eutrophic lake, which includes lack of oxygen in the hypolimnion during the summer stagnation period, continued eutrophication and extinction become rapid.

Einsele, W. 1938. Über chemische und colloidale-chemische Vorgänge in Eisen-Phosphor-Systemen unter limnochemischen und limnogeologischen Gesichspunken. Arch. f. Hydrobiol., Vol. 33, pp. 361–387.

Mortimer, C. H. 1941. The Exchange of Dissolved Substances between Mud and Water in Lakes. I and II. Journal of Ecology, Vol. 29, No. 2, pp. 280–329.

Tucker, A. 1957.

The Relation of Phytoplankton Periodicity to the Nature of the Physico-Chemical Environment with Special Reference to Phosphorus. I. Morphometrical, Physical and Chemical Conditions. American Midland Naturalist, Vol. 57, pp. 300–333.

The investigation was carried on for 16 months at Douglas Lake, Michigan, with water samples being collected and phosphorus determinations being made every two weeks.

At the surface, total phosphorus fluctuated between 7 and 14 micrograms per liter, at the 12-meter depth (lower limit of the epilimnion) between 7 and 15 micrograms per liter. At the 20-meter depth, between July 3 and September 16, the amount of total phosphorus increased from 10 micrograms per liter to 641. Seasonal variation in inorganic phosphorus (soluble) followed closely the variation in total phosphorus, although smaller in amount. Analysis of a vertical series of samples showed that the most constant fraction of phosphorus was the soluble organic phosphorus, never exceeeding 9 micrograms per liter regardless of the depth at which the sample was taken.

The pH was 8.0–8.4 in the epilimnion and between 7.0 and 8.0 in the hypolimnion.

Tucker, A. 1957a.

The Relation of Phytoplankton Periodicity to the Nature of the Physico-Chemical Environment with Special Reference to Phosphorus. II. Seasonal and Vertical Distribution of the Phytoplankton in Relation to the Environment. American Midland Naturalist, Vol. 57, pp. 334–370.

Toward the end of the summer, oxygen was absent at the bottom of the hypolimnion in Douglas Lake, Michigan, but phosphorus could not be detected in this bottom area until about 8 weeks after the disappearance of the oxygen. It was concluded that the reason for the lack of analyzable phosphorus was that iron and phosphorus can exist independently only when oxygen is absent and that if oxygen is introduced, the iron and phosphorus will combine to form an insoluble ferric phosphate precipitate. When oxygen disappears from bottom waters, the ferric complexes are reduced, forming ferrous complexes which are soluble.

Tucker, J. M., D. R. Cordy, L. J. Berry, W. A. Harvey, and T. C. Fuller. 1961.

Nitrate Poisoning in Livestock. California Agricultural Experiment Station Extension Service, University of California Circular 506, 9 pp.

Nitrates, absorbed from the soil by most plants, serve as a source of nitrogen which plants convert into proteins and other nitrogen-containing compounds. Normally functioning plants usually contain relatively small amounts of nitrate because the nitrate is converted into other nitrogenous compounds almost as soon as it is absorbed. Under certain conditions, however, some plants may accumulate fairly high concentrations of nitrate. While these concentrations are not toxic to the plant itself, animals feeding on such plants may sometimes suffer fatal poisoning.

Nitrate itself is not very toxic, but is readily converted into nitrite. Probably most of the conversion of nitrate to nitrite takes place in the animal digestive tract, although some field studies indicate that nitrite may already be present in the plants before they are eaten. Nitrite converts the hemoglobin in red blood cells to methemoglobin, which cannot transport needed oxygen from the lungs to the body tissues. Thus, animals affected with nitrate poisoning show general symptoms of oxygen deficiency.

Ruminants, particularly cattle, are the principal victims of nitrate poisoning because of the large amounts of plant material they eat and the action of microorganisms in the rumen. Sheep and swine are less susceptible. There appears to be few recorded cases of horses dying from nitrate poisoning under pasture or range conditions.

Factors affecting nitrate accumulation in plants include the stage of the plant's growth (the pre-blooming period has the highest accumulation), an ample supply of available nitrate in the soil, an adequate moisture supply, an acid rather than an alkaline soil, relatively low temperatures (around 55° F), and reduction in light intensity. An excess of phosphate tends to retard nitrate absorption.

Plants are considered as potentially toxic if they contain nitrate amounting to more than 1.5 percent expressed as KNO_3 on a dry weight basis. This is 15,000 ppm KNO_3 or 2,078 ppm N.

Plants that have been involved in nitrate poisoning or are capable of accumulating appreciable amounts of nitrate include:

PLANT	COMMON NAME
Amaranthus blitoides	Prostrate pigweed.
A. graecizans	Tumbling pigweed.
A. retroflexus	Rough pigweed.
Ammi majus	Bishop's weed.
Amsinckia douglasiana	Douglas' fiddleneck.
A. intermedia	Common fiddleneck.
Apium graveolens	Celery.
Avena sativa	Oats.
Beta vulgaris	Sugar beet.
B. vulgaris var. *rapa*	Mangel.
Bidens frondosa	Beggar-ticks.
Brassica campestris	Turnip.
B. napobrassica	Rutabaga .
B. napus	Rape.
B. oleracea vars	Brocolli, Kale, Kohlrabi.
B. rapa	Turnip
Bromus catharticus	Rescue grass.
Chenopodium album	Lamb's-quarters.
C. ambrosioides	Mexican tea.
C. californicum	Soap plant.
C. murale	Nettle-leaf goosefoot.
Cirsium arvense	Canada thistle.
Cleome serrulata	Rocky Mountain bee plant.
Conium maculatum	Poison hemlock.
Convolvulus arvensis	Wild morning-glory.
Cucumis sativa	Cucumber.
Cucurbita maxima	Hubbard squash.
Daucus carota	Carrot.
Eleusine indica	Goose grass.
Euphorbia maculata	Spotted spurge.
Glycine max	Soybean .
Gnaphalium purpureum	Purple cudweed .
Haplopappus venetus	Coast goldenbush.
Helianthus annuus	Common sunflower.
Helianthus tuberosus	Jerusalem artichoke.
Hordeum vulgare	Barley.
Kochia americana	Fireball.
Lactuca sativa	Lettuce.
L. scariola	Prickly lettuce.
Linum usitatissimum	Flax .
Malva parviflora	Cheeseweed.
Melilotus officinalis	Yellow sweet clover.
Montia perfoliata	Miner's lettuce.
Panicum capillare	Witch grass.
Parkinsonia aculeata	Horse bean.
Pastinaca sativa	Parsnip.
Plagiobothrys sp.	Popcorn flower.
Rafinesquia californica	California chicory.
Raphanus sativus	Radish.
Salsola kali	Russian thistle.

PLANT	COMMON NAME
Secale cereale	Rye.
Silybum marianum	Milk thistle.
Solanum carolinense	Carolina horse nettle .
S. nigrum	European black nightshade.
Sonchus asper	Prickly sow-thistle.
S. oleraceus	Common sow-thistle.
Sorghum halepense	Johnson grass.
S. sudanense	Sudan grass.
S. vulgare	Sorghum.
Thelypodium lasiophyllum	California mustard.
Tribulus terrestris	Puncture vine.
Triticum aestivum	Wheat.
Verbesina encelioides	Crownbeard.
Zea mays	Corn.

Vaccaro, R. F. 1964.

Available Nitrogen and Phosphorus at the Biochemical Cycle in the Atlantic of New England. Journal of Marine Research, Vol. 21, No. 3, pp. 284–301.

During August, when only trace amounts of nitrate persist in the photic layer, ammonia appears to be the major source of available nitrogen. By late summer, nitrogen assimilation by marine phytoplankton in the surface waters off New England had reduced nitrate to trace amounts close to the limit of sensitivity of the analytical method employed. Ammonia persists throughout the summer at about half of its winter concentration, and by August it has become the most abundant source of plant nitrogen. Conversely during winter, although higher concentrations of each type of nitrogen are present, nitrate-nitrogen is five or six times more abundant than ammonia. It appears that the relative abundance of ammonia as opposed to nitrate during summer in the euphotic waters off New England coincides with maximum stratification of the water column because of increased surface temperatures. Until the occurrence of active nitrification within the upper layer is more conclusively demonstrated, it must be assumed that, at such times, the major impetus to the nitrogen cycle is provided by ammonia because of its more rapid exchange between organisms and environment and because of its direct addition from the atmosphere in association with rain. The annual variation in available phosphorus within these waters, unlike that of nitrogen, is much less pronounced, and excess amounts are the rule throughout the year.

The analyses of particulate nitrogen and phosphorous provide a quantitative basis for assessing the extent of seasonal adaptation to the summer supply of available nitrogen and phosphorus. When nitrate was virtually absent from the upper fifty meters during August, the phytoplankton contained nitrogen and phosphorus on a dry weight basis at a ratio corresponding to 12:1. This condition was accompanied by generally higher ratios up to 20:1 in the coarser net material. Competent ratios measured by Harris and Riley (1956) were cited for Long Island Sound as 12.6:1 for August phytoplankton and 20.6:1 for July zooplankton. For March of the same year, when large amounts of available nitrogen were present, the same authors reported a ratio of 17.2:1 for Long Island Sound phytoplankton.

Harris, E. and G. A. Riley. 1956.
Oceanography of Long Island Sound, 1952–54.
VIII. Chemical Composition of the Plankton.
Bull. Bingham Oceanogr. Coll., Vol. 15, pp. 315–323.

Vallentyne, J. R. 1952.
Insect Removal of Nitrogen and Phosphorus Compounds From Lakes. Ecology, Vol. 33, pp. 573–577; Water Pollution Abstracts, Vol. 26, No. 11, Abs. No. 1861.

To determine the amounts of nitrogen and phosphorus removed from lakes by aquatic insects which leave the water in the adult stage, a study was made of the concentration of total nitrogen and phosphorus in adult insects trapped as they emerged from the water in Lake Opinicon, Ontario. On an average, 136 insects emerged per day per square meter of surface and these had a fresh weight of 69.2 mg and contained 2.26 mg of total nitrogen and 0.15 mg of total phosphorus. It is calculated that in Winona Lake, Indiana, where the amount of organic sediment has been determined, the loss of organic matter by emergence of insects was less than 1 percent of the amount of organic sediment deposited annually.

VanVuren, J. P. J. 1948.
Soil Fertility and Sewage. Dover Publications Inc., New York, 236 pp.

The average human inhabitant of a European city excretes 107 pounds per year solids and 964 pounds per year liquids for a total of 1,071 pounds. This contains 75.8 pounds of dry matter, 11.4 pounds of nitrogen and 2.6 pounds of phosphoric acid. The average composition of fresh human feces is 1 percent nitrogen and 1.10 percent phosphoric oxide (PO); the composition of urine is 0.6 percent nitrogen and 0.17 percent PO.

The quantity of manure voided by animals varies with type, climate and food. Roughly for 1,000 pounds of live weight, cows excrete 22,000 pounds of solids and 6,800 pounds of liquids per year; horses, 13,000 and 2,600 pounds, respectively. Yearly fertiliser constitutents were given as follows:

	Nitrogen (pounds)	Phosphoric acid (pounds)
Horse	128	42
Cow	158	28
Sheep	119	44
Pig	180	104

The water hyacinth was first introduced into the United States from Venezuela and exhibited at the New Orleans Cotton Exposition in 1884. Its rapid spread in the new environment soon made it a nuisance. Random samples of a compost manure of water hyacinth have shown a nitrogen percentage of 1.12 on a dry weight basis. Under optimum conditions the nitrogen percentage may range to 2.23 percent on a dry weight basis and the phosphoric oxide 0.86 to 8.0 percent. Based on the average weight of plants per square foot, half an hour after their removal from water, it was calculated that an acre of well-grown plants would weigh approximately 96 tons. The yield was assumed to range fom 4.3 to 6.7 tons of dry matter per month. It was postulated that as a true water plant, water hyacinth was especially suitable for effluent lakes with its major difficulty being its bulk and high percentage of water. Under suitable climatic conditions, one acre with cropping would remove 3,075 pounds of nitrogen per year, the discharge of 220 persons per annum.

Voigt, G. K. 1960.
Alteration of the Composition of Rainwater by Trees. American Midland Naturalist, Vol. 63, pp. 321–326.

The investigation was concerned with the nutrient content of rainwater, its modification by three forest cover types, and the net nutrient return to forest soils resulting from the addition of rainwater.

The area of study was located in southern Connecticut, a region which receives about 45 inches of precipitation per year. The water samples were collected from two storms, one in May and one in September.

The composition of rainwater collected in an open area in mg/l was as follows:

	May	September		May	September
Nitrogen (total)	0.05	0.07	Potassium	0.2	0.6
Phosphorus	.01	.01	Calcium	.6	.8

The differences in potassium and calcium content between May and September are probably related to the proximity of the study area to the highly industrial region of the east. This, together with differences in wind direction and storm movements, could cause great differences in the amount of air pollution.

Walton, G. 1951.
Survey of Literature Relating to Infant Methemoglobinemia Due to Nitrate-Contaminated Water. American Journal of Public Health, Vol. 14, No. 8, pp. 986–996.

Although methemoglobinemia may result from congenital heart diseases, or from the ingestion, inhalation, or absorption, or the medicinal administration, of any one of several drugs or chemicals, an important cause of cases in infants is the ingestion of water high in nitrate.

The permissible nitrate-nitrogen (NO$_3$-N) concentration in water which may cause infant methemoglobinemia when used in a feeding formula is dependent on the individual's susceptibility, the increase in nitrate-nitrogen concentration that is due to boiling the water, the quantity of boiled water consumed per day per unit weight of the infant, the duration of exposure to the high nitrate water, and possibly other factors.

Comly (1945) considered it inadvisable to use well water containing more than 10 or 20 mg/l nitrate-nitrogen (NO$_3$-N) in preparing an infant's feeding formula. No cases have been reported which were associated with water containing 10 mg/l nitrate nitrogen or less, and the nitrate nitrogen content was less than 20 mg/l for only 2.3 per cent of the cases for which data are available.

According to Sarles, et al. (1940), the principal sources of nitrogenous matter in the soil are the decomposition products of plants, animals and microorganisms; the liquid and solid wastes of animal metabolism; and fertilizers added to enrich the soil. The possibility of geological formations containing appreciable amounts of nitrates must also be considered. Since bacteria are essential in the production of nitrates from organic nitrogen, factors influencing their activity affect the nitrate content of the soil. Sarles, et al. (1940), note that nitrification takes place only when the soil contains buffering substances which neutralize the nitric acid and maintain a pH around 6.5 to 8.0; when aerobic conditions, such as result from plowing, cultivating, etc., are maintained; when soil contains only 50 per cent of its water-holding capacity; when ammonia salts and other nutrient elements are present in the soil; and at temperatures above 50° and below 100° F.

Comly, H. H. 1945.
Cyanosis in Infants Caused by Nitrates in Well Water.
Journal American Medical Association, Vol. 129, pp. 112–116.

Sarles, W. B., Frazier, W. C., and McCarter, J. R. 1940.
Bacteriology (Rev. Ed.), Madison, Wis.: Kramer Business Service.

Webster, G. C. 1959.
Nitrogen Metabolism in Plants. Row, Peterson and Co., Evanston, Illinois, 152 pp.

The nitrogenous substances assimilated by plants can be divided into four major classes: organic nitrogen, ammonia nitrogen, nitrate nitrogen, and molecular nitrogen. Although a few plants (certain bacteria and algae) can assimilate all four forms of nitrogen, the great majority can utilize only nitrate, ammonia, and various forms of organic nitrogen as shown in the following table:

Utilization of various forms of nitrogen by plants

Organism	Organic nitrogen	Ammonia nitrogen	Nitrate nitrogen	Molecular nitrogen
Some fungi, some bacteria, and some species of *Euglena*	X			
Some fungi, some bacteria	X	X		
Most bacteria, fungi, algae and higher plants	X	X	X	
Some bacteria and blue-green algae	X	X	X	X

Weibel, S. R., R. J. Anderson, and R. L. Woodward. 1964.
Urban Land Runoff as a Factor in Stream Pollution. Journal Water Pollution Control Federation, Vol. 36, No. 7, pp. 914–924.

Stormwater runoff from a 27-acre residential and light commercial drainage basin with separate sewers in the Cincinnati, Ohio, area contained 2.5 and 8.9 pounds per acre per year PO_4 and total nitrogen-N, respectively. Based on a population density of 9 persons per acre and a flow of 100 gallons per capita per day, the comparative raw sanitary sewage would contain 27 and 81 pounds per acre per year PO_4 and total N, respectively. Phosphates in stormwater runoff constituted 9 percent of the phosphates in the calculated raw sanitary sewage and total nitrogen-N composed 11 percent of the total nitrogen in sewage.

Whipple, G. C., G. M. Fair, and M. C. Whipple. 1948.
The Microscopy of Drinking Water. John Wiley and Sons, New York, 586 pp.

Free ammonia indicates organic matter in a state of decay. Nitrates tend to increase in cold weather after the growing season, and free ammonia and nitrites decrease because of inhibited bacterial action. In the spring ammonia and nitrites usually increase in advance of growing plant life.

"Putrefaction and decay of dead organisms and waste materials give rise to ammonia compounds that are assimilated by some plant organisms; usually the nitrogen of the ammonia compounds is carried to nitrites and nitrates by oxidizing bacteria. The oxidized nitrogen becomes one of the chief foods of plants in building up protein. To a slight extent oxidation is sometimes reversed and nitrates are reduced to nitrogen that may be dissolved in the water or escape to the air, thus representing a loss. Plant protein becomes animal protein. Finally death of both plants and animals returns nitrogen to the process of putrefaction and decay. A short circuit in the cycle is the digestion of protein with elimination of urea, from which ammonia is derived without putrefaction."

Whitford, L. A. and R. C. Phillips. 1959.
Bound Phosphorus and Growth of Phytoplankton. Science, Vol. 129, No. 3354, pp. 961–962.

No correlation was found between phytoplankton pulses in four North Carolina ponds and variations in bound (total) phosphorus. It was concluded that the interaction of a complex of chemical and physical factors produces both seasonal fluctuations and sporadic blooms of phytoplankton.

Winks, W. R., A. K. Sutherland, and R. M. Salisbury. 1950.
Nitrite Poisoning in Pigs. Qd. J. Agric. Sci., Vol. 71, pp. 1–14; Water Pollution Abstracts, Vol. 25, No. 10, Abs. No. 1528.

Pigs fed with soups prepared with well water containing 1,740 to 2,970 mg/l sodium nitrate died from methemoglobinemia. Experiments showed that 0.09 grams of sodium nitrite per kg. of body weight was fatal to pigs and it was concluded that poisoning was due to nitrites derived from the nitrates.

Wurtz, A. G. 1962.
Some Problems Remaining in Algae Culturing. Algae and Man (D. F. Jackson, editor), Plenum Press, pp. 120–137 (1964).

In ponds, the introduction of phosphates into the water raises the pH of the mud, accelerating the reactions of decomposition in the mud, and liberating from the mud not only inorganic but also organic nitrogen.

Zicker, E. L., K. C. Berger and A. D. Hasler. 1956.
Phosphorus Release from Bog Lake Muds. Limnology and Oceanography, Vol. 1, No. 4, pp. 296–303.

In laboratory experiments the percentage, as well as the amount of phosphorus released to the water from radioactive superphosphate fertilizer placed at various depths below the mud surface in an undisturbed mud-water system was indicated to be very small. There was virtually no release of phosphorus from fertilizer placed at depths greater than one-fourth inch below the mud surface. There was a higher percentage of soluble phosphorus contained in the water samples taken near the mud surface than in water samples taken at greater distances above the mud surface. The radiophosphorus placed one-half inch below the mud surface showed only a very slight tendency to diffuse into the water, while the radiophosphorus placed at the one-inch depth did not diffuse into the water at all.

Zilversmit, D. B., C. Entenman, and M. C. Fishler. 1943.
On the Calculation of "Turnover Time" and "Turnover Rate" from Experiments Involving the Use of Labeling Agents. Journal of General Physiology, Vol. 26, No. 3, pp. 325–331.

The term "turnover" refers to the process of renewal of a given substance which may be accomplished by (1) the incorporation of labeled atoms into a substance, (2) the entering of a labeled substance into a tissue, or (3) a combination of the above two processes. The "turnover rate" of a substance in a tissue is the amount of the substance that is turned over by that tissue per unit of time. The "turnover time" of a substance in a tissue is the time required for the appearance or disappearance of an amount of that substance equal to the amount of that substance present in the tissue. If the rate of appearance of a substance in a tissue is "a" and the amount of that substance present in that tissue is "b," the turnover time is $\frac{b}{a}$.

U.S. GOVERNMENT PRINTING OFFICE: 1965

Definitions and Equivalents

cfs=cubic feet per second; cfs$\times$448.8=gallons per minute; cfs$\times 5.4\times 10^{6}$=pounds per day

g/l=grams per liter; g/l$\times$1,000=parts per million

g/m^2=grams per square meter; g/m$^2\times$8.922=pounds per acre

ha=hectare; ha$\times$2.471=acres

kg=kilograms; kg$\times$2.2=pounds

kg/ha=kilograms per hectare; kg/ha$\times$0.8922=pounds per acre

metric tons$\times$2,204=pounds

μg-at P/g=microgram atoms phosphorus per gram=31 parts per million phosphorus

μg-at P/l=microgram atoms phosphorus per liter=31 parts per billion phosphorus

μg/g=micrograms per gram=ppm

μg/l=micrograms per liter=ppb; μg/l$\times 10^{-3}$=parts per million

μg/m^2=micrograms per square meter; μg/m$^2\times 8.92\times 10^{6}$ =pounds per acre

mg/g=milligrams per gram; mg/g$\times 10^{3}$=ppm

micromoles P per 100 grams$\times$0.31=parts per million

mg/l=milligrams per liter=parts per million

mg/m^3=milligrams per cubic meter; mg/m$^3\times$0.00272 =pounds per acre-foot

mg/m^2=milligrams per square meter; mg/m$^2\times$8,922 =pounds per acre

mg %=milligrams percent=milligrams in 100 grams=1 part in 100,000 parts wet weight; mg %$\times$0.1=ppm

mgd=million gallons per day; mgd$\times$1.547=cubic feet per second

ppb=parts per billion

ppm=parts per million

P_2O_5=phosphorus pentoxide; $P_2O_5\times$0.436=P

PO_4=phosphate; $PO_4\times$0.326=P

NO_3=nitrate; $NO_3\times$0.226=N

Parts per million$\times$cubic feet per second$\times$5.4=pounds per day (gallons per minute$\times 2.228\times 10^{-3}$=cubic feet per second)

Parts per million$\times$8.34$\times$gallons per day$\times 10^{-6}$=pounds per day (gallons per minute$\times$1,440=gallons per day)